WORK ACTIVITIES AND RESPIRATORY AND PHYSICAL HEALTH OUTCOMES AMONG INDUSTRIAL HOG OPERATION WORKERS: COMMUNITY-DRIVEN DATA COLLECTION TO INFORM APPROPRIATE PROTECTIVE ACTIONS

by

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ABSTRACT

Airborne dusts, noxious gases, endotoxins, and microbial exposures from industrial hog operations (IHOs) have been shown to adversely affect IHO workers' and neighbors' health and quality of life. For IHO worker respiratory disease in particular, knowledge gaps remain about the temporal dynamics of exposure-response relations and specific factors that might mitigate exposure and disease burdens. Prior studies to estimate respiratory health effects have focused mainly on comparisons of IHO worker to non-worker populations or pre- *vs.* post-IHO work shift measurements.

This dissertation aims to advance the understanding of temporal relationships between self-reported IHO work exposure activities and respiratory and physical health outcomes, including those activities which may be protective. It uses data from an IHO worker cohort with exposures and outcomes measured in two-week intervals over the course of 16 weeks (4 months) of follow-up. It also employs an underutilized fixed-effects regression method for repeated-measures data, which eliminates confounding from measured and unmeasured time-invariant factors as each IHO worker's time-varying exposure and outcome measures are compared to his/her mean exposure and outcome. Further, the dissertation contributes to lessons learned from a community-driven pilot study designed to investigate evidence of swine-specific fecal contamination of household surfaces at residences proximal to IHOs and the nares of those living in the home.

For **Aim 1**, an analysis was conducted of baseline (n=103 individuals) and longitudinal (n=101 individuals with 782 biweekly person-records) associations of self-reported IHO work exposure activities and self-reported respiratory and physical health

outcomes within the four-month-long IHO worker cohort. At baseline, longer time employed on any IHO and workplace activities that constituted increased frequency of contact with pigs, dustiness, and frequency of conducting cleaning activities were associated with increased odds of a variety of respiratory and physical health symptoms. Among 39 exposure-response associations examined, five odds ratios (ORs) and 95% confidence intervals (CIs) were above and not overlapping the null (OR range: 2.19 to 32). In longitudinal fixed effects analyses, lower odds of symptoms were seen with increased frequency of personal protective equipment (PPE) use. Among 15 exposure-response associations examined, three ORs (95% CIs) were below and not overlapping the null (OR range: 0.04 to 0.09). Handwashing frequency at or above *vs*. below the median of eight handwashes per shift was associated with 0.32 (95% CI: 0.12, 0.83) times the odds of reporting at least one respiratory symptom in the past week.

For **Aim 2**, a baseline and longitudinal analysis of the four-month-long IHO worker cohort was conducted to assess the relationships between work activities and lung function (as measured by spirometry). At baseline, time spent on any IHO (average work week of seven days *vs.* less than seven days, years worked on any IHO, and percentage of life working on any IHO) was associated with decreases in predicted lung function (9 out of 30 ß estimates were negative in direction and did not overlap the null [ß range: -12.35 to -4.32]). Over time, increased PPE utilization was associated with decreases in lung function, opposite from the hypothesized direction of association. In further explorations of the relationship between PPE use and lung function, it was observed that as IHO barn and work conditions worsened IHO workers were more likely to wear protective coveralls but less likely to wear protective face gear (mask or eye protection). This

suggests that IHO workers may not be donning the appropriate PPE to protect their respiratory system, particularly during working conditions when it is most warranted.

For **Aim 3**, a community-driven citizen science pilot study was conducted to assess ambient airborne particulate matter (PM) and bacterial loads (including the swine-specific fecal bacterial source tracking marker Pig-2-Bac) on surfaces of the homes and within the human nares of adults and children (<7 years of age) at: 1) IHO worker households; and (2) community resident comparator households (with no known livestock exposure). For the purposes of this dissertation, lessons learned are presented from working with community partners to: (1) develop and finalize the research questions and study design for the pilot study; (2) train community organizers in pilot study data collection; and (3) evaluate the quality and completeness of data collected by community organizers who used mobile-devices (tablets) to complete participant interviews and collected household surface (inside and outside) and human nasal swab samples that were sent to be tested for bacterial contamination. Among 26 industrial hog operation (IHO) worker and 23 community resident households enrolled, 20 (n=41 individuals) and 18 (n=36 individuals), respectively, met eligibility criteria (at least one child <7 years of age living in the household) for inclusion in the pilot study. Of the surveys administered to participants, 2.4% of questions (463 of 18,932) were complete – with no statistically significant differences between those eligible *vs.* ineligible or IHO household *vs.* community referent. The average number of questions missing was 11 per survey and reduced to only 4 after weekly data evaluations were implemented in week 10. An identified challenge was failure of conditional programming of the tablet software during study eligibility determination in the field (data entry screens did not trigger a stop an

enrollment alert for children seven years of age and older) which led to enrollment of 11 households (eight IHO and three community resident) that were later determined to be ineligible upon further data review. Though the sample size was small, responses among n=18 enrolled IHO workers indicated that their employer provided them with N95 respirator facemasks and some training in their use. Lessons learned include a need to reconcile advantages of novel mobile device data collection technologies and software with the practical demands of timely tracking, verification, and checking of system performance during and after field data collection, which may exceed the practical capacity of some community-driven research partners. Future studies should focus on development and implementation of processes to make mobile device data collection tools and protocols to be understandable, feasible, accessible, reliable, repeatable, and accurate.

This dissertation research was innovative in three key areas: (1) the ability, through long-standing community-driven research partnerships, to engage with hard-to-reach livestock workers who identify predominantly as a race/ethnicity that is under-represented in IHO worker studies, and lack traditional health and safety supports; (2) the contribution to the understanding of time-varying exposure-response dynamics of IHO work exposures and activities; and (3) the lessons learned from a novel community-driven pilot study designed to assess microbial loadings on household environmental surfaces and the nares of those living proximal to IHOs.

In conclusion, IHO exposure and work activities were associated with adverse respiratory and physical health outcomes among IHO workers. It was shown that the use of PPE can decrease these risks, but not eliminate them. Lessons learned related to data quality and completeness may improve future community-driven citizen science data collection efforts. Further research is needed to understand the complex exposures from IHOs to protect worker and community populations that surround these operations.

"I may not live to see our glory, but I will gladly join the fight. And when our children tell our story, they'll tell the story of tonight." — Lin-Manuel Miranda, *Hamilton;* act 1

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PREFACE

This dissertation is the culmination of a body of research conducted with my co-advisors, co-authors, and collaborators during my doctoral studies in the Department of Environmental Health and Engineering at the Johns Hopkins Bloomberg School of Public Health. It is organized in a manuscript format.

First, specific aims are presented and then an overview of, and the motivations behind, this dissertation are provided. Additionally, the use of an underutilized though valuable statistical tool (fixed-effects regression analysis) in this work and the value of the tool at-large is discussed. Each of the analyses conducted, organized into three chapters, is then reviewed. The first chapter evaluates the cross-sectional and longitudinal associations between self-reported on-IHO exposures and health outcomes in a cohort of IHO workers followed for 16 weeks. The second chapter evaluates the association between self-reported on-IHO exposures, health outcomes, and lung function in the same worker cohort. The third chapter explores the methodology behind the data collected from a separate pilot project within the same community as the worker cohort, but conduced four years later, to investigate exposure to airborne contaminants from IHOs found within the community. Noteworthy results, miscellaneous to the three main chapters, are then presented. Finally, the discussion provides an overview of the research findings, strengths and limitations of the analyses, implications of the research, proposed next steps, and final conclusions.

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I would also like to acknowledge our collaborators at the Rural Empowerment for Community Help (REACH), in particular Devon Hall. His dedication to this work will help us not only better understand the true impact from hog operations but improve life in his community and around the world. I would also like to acknowledge the CLF-Lerner Fellowship program for its gracious funding support. Without these partnerships, this work would not have been possible.

Finally, I would like to thank those not involved in my research who have supported me throughout the past four years: my fellow EHE cohort, who has celebrated the good times and been a strong support through the bad; students ahead of me who have generously provided guidance, in particular Drs. Katherine Moon and Joan Casey; my family, and my friends, who are like family; and my loving and forever-patient husband, who allows me to pursue my dreams, no matter how crazy they are or how many cross-country moves they entail.

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MISCELLANEOUS RESULTS

ABBREVIATIONS

Akaike's information criterion (AIC)
American Thoracic Society (ATS)
Animal equivalent unit (AEU)
Animal feeding operation (AFO)
Body mass index (BMI)
Chronic obstructive pulmonary disease (COPD)
Community-based participatory research (CBPR)
Concentrated animal feeding operations (CAFO)
Concentrated animal operations (CAO)
Confidence interval (CI)
Environmental impact assessment (EIA)
Forced expiratory flow at 25-75% of the pulmonary volume (FEF25-75%)
Forced expiratory volume in one second (FEV_1)
Forced expiratory volume in six seconds (FEV_6)
Forced vital capacity (FVC)
Generalized estimating equations (GEE)
Industrial food animal production (IFAP)
Industrial hog operation (IHO)
Institutional review board (IRB)
Interquartile range (IQR)
Johns Hopkins University (JHU)
Livestock-associated multidrug-resistant *S. aureus* (LA-MDRSA)
Livestock-associated methicillin-resistant *S. aureus* (LA-MRSA)
Methicillin-resistant *S. aureus* (MRSA)
Methicillin-susceptible *S. aureus* (MSSA)
Missingness not at random (MNAR)
Multidrug-resistant *S. aureus* (MDRSA)
North Carolina (N.C.)
National Institute for Occupational Safety and Health (NIOSH)
Nutrient management plan (NMP)
Odds ratio (OR)
Polymerase chain reaction (PCR)
Particulate matter (PM)
Peak expiratory flow rate (PEFr)
Personal protective equipment (PPE)
Prevalence ratio (PR)
Prevalence odds ratio (POR)
Relative risk (RR)
Rural Empowerment Association for Community Help (REACH)
Socioeconomic status (SES)
U.S. Environmental Protection Agency (EPA)
University of North Carolina at Chapel Hill (UNC)

SPECIFIC AIMS

The consolidation of small-scale farms into large, vertically integrated industrial concentrated animal feeding operations (CAFOs) has given rise to numerous environmental and occupational health concerns. CAFO-related air pollution,[1-7] water pollution,[8,9] occupational hazards,[10,11] and community health hazards[12-16] have been identified. Among CAFO workers[15,17-20] and neighbors[21-24] there is a substantial burden of respiratory disease related to air pollutants on and emitted from CAFOs. Industrial hog operation (IHO) workers appear to suffer the greatest burden of respiratory symptoms relative to other livestock workers (*e.g.,* broiler chicken, turkey, cattle, or veal calf).[25,26] These respiratory health symptoms have been noted in the literature to be a risk factor for chronic respiratory conditions, infection, and disease.[27-29] IHO workers exhibit asthma-like syndrome,[30] chronic bronchitis,[31] mucosal membrane irritation,[32] and organic dust toxic syndrome.[33]

Although IHO-related respiratory health effects are recognized, the specific job activities of IHO workers that contribute to adverse symptoms and the protective measures that could decrease adverse symptoms remain poorly understood. For example, the use of masks on the jobsite has not been mandated, in part, due to a lack of consensus among experts on when they should be employed.[34] Given that an estimated 32,573 people are employed in hog farming in the United States,[35] this burden of occupational respiratory disease warrants further investigation.

In communities where populations live[13,14,36] or attend school[2,6] proximal to IHOs, respiratory health effects have also been documented in adults and children.[24] Southeastern North Carolina has a high density of IHOs close to homes, making it, from an epidemiologist's standpoint, an ideal location to study human health impacts from these operations. An estimated 58,505 people reside in Duplin County[37] alongside 865 pig waste lagoons receiving waste from an estimated 2.3 million pigs.[38] Bordering Duplin County to the east, Sampson County has similar figures (2.1 million pigs, 774 waste lagoons,[38] and 63,431 people[39]), as does Bladen County to the southwest of Sampson (756,000 pigs, 284 waste lagoons,[38] and 35,190 human residents.[40]

A long-term goal of this work is to understand how changes in exposure to IHO-related air pollutants are temporally related to acute changes in respiratory disease and mucus membrane irritation among IHO workers and neighbors and to identify modifiable factors that could reduce disease burden in these populations. The objectives of this dissertation are to: (1) determine whether changes in IHO work activities are related to changes in self-reported health outcomes among IHO workers; (2) determine whether changes in IHO work activities are related to acute changes in lung function (spirometry) among IHO workers; (3) assess the relation between protective measures employed at any IHO and physical health; and (4) report the lessons learned about citizen scientist training and field work to collect data about IHO-related exposures at homes proximal to IHOs.

It was hypothesized that changes in acute IHO work activities would be temporally associated with changes in acute respiratory and physical health outcomes among IHO workers via self-reported symptoms and objective spirometry measurements. Further it was hypothesized that those with chronic IHO work exposures will report more frequent chronic symptoms and will exhibit worse baseline lung function, even in the face of potential bias related to the healthy-worker survivor effect.

To test these hypotheses data was used from a 2013-2014 cohort of 103 IHO workers enrolled from Duplin, Sampson, and Bladen County, N.C. IHO workers completed a baseline enrollment session and biweekly (*i.e.,* every two weeks) follow-ups for four months and reported IHO work activities, respiratory health outcomes, and completed spirometry measurements via Koko and Piko-1 monitors (nSpire Health, Longmont, Colorado, USA). The specific aims were the following (**Figure SA.1**):

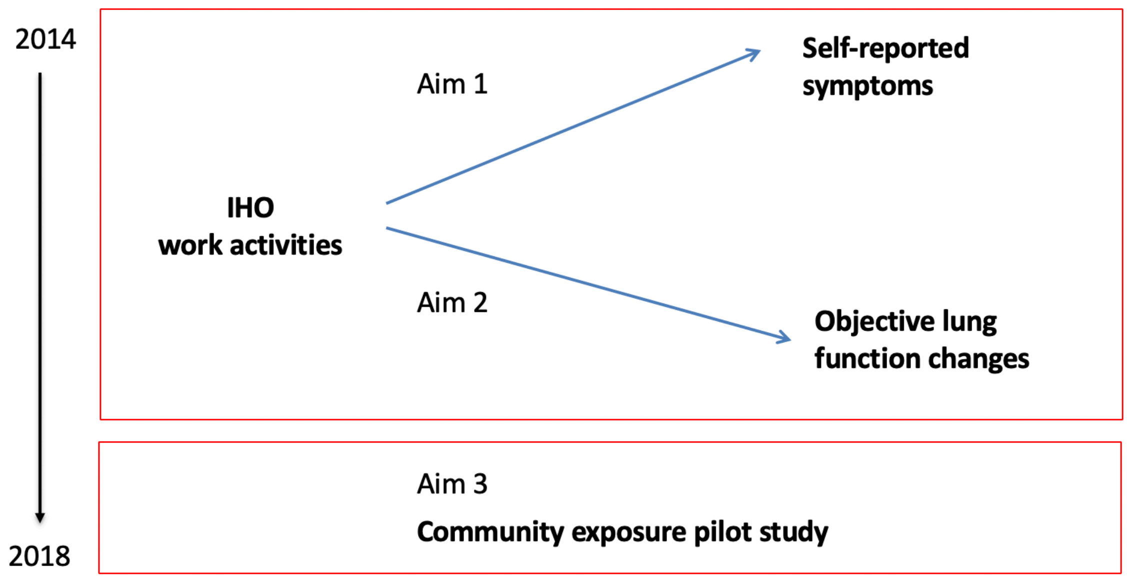

Figure SA.1. Flow diagram of the two studies which enrolled different people from the same community in southeastern North Carolina.

Aim 1: Determine whether changes in IHO work activities and conditions are related to self-reported respiratory symptoms cross-sectionally and longitudinally in a cohort of IHO workers (Duplin, Sampson, and Bladen County, N.C., 2013-2014).

Aim 2: Determine whether changes in IHO work activities and conditions are related to changes in lung function cross-sectionally and longitudinally in a cohort of IHO workers (Duplin, Sampson, and Bladen County, N.C., 2013-2014).

To achieve aims 1 and 2, extant survey and spirometry data were analyzed.

Aim 3: To report lessons learned related to the methods and approach for training citizen scientists to collect human and environmental data for research designed to measure off-site migration of IHO-specific microbial contamination at residences of IHO workers and community residents living proximal to a high density of IHOs (Duplin County, N.C., 2017-2018).

Ensuring the health of IHO workers and neighbors requires improving our understanding of the impact of these operations. By analyzing data from a repeated-measures study in one population of IHO workers and by conducting a pilot study in a community population these gaps can be filled.

This dissertation yielded four outcomes. First, it provided insight into IHO-related respiratory disease among IHO workers who possess demographic and occupational characteristics that, to our knowledge, have not been studied in the United States. IHO workers in the present cohort were 88 percent non-black Hispanic/Latino and 12 percent black, performed the day-to-day intensive animal production activities at the IHOs where they work, and were 45% female. This is in contrast to prior studies of IHO worker respiratory disease, which involved primarily Caucasian male IHO owner-operators and may not have had the same job tasks and exposures as the day-to-day Latino workers. Second, it provided evidence of a relation of longer time spent on-IHO and intense exposure to pigs and dusty/dirty conditions on-IHO with adverse respiratory and physical health symptoms and declines in lung function. Third, it contributed to an understanding of modifiable risk factors and behavior changes that may reduce respiratory disease burden among IHO workers, including the use of personal protective equipment (PPE). And finally, using a pilot study, lessons learned from novel community-driven environmental epidemiologic research are presented along with insights into the masks being used and when they are being used on these livestock operations.

INTRODUCTION

Overview

This chapter reviews the existing literature, details gaps in knowledge, and provides the motivation for the dissertation. The following topics are covered: (1) a brief overview of the expansion of the industrial mode of swine production in the U.S.; (2) what is known about airborne IHO exposures and respiratory health outcomes, including lung function; (3) what is known about use of personal protective equipment (PPE) and other control measures on IHOs; and (4) what is known about the association between residential distance from IHOs and community respiratory health.

CAFOs and regulations of animal waste

The U.S. Environmental Protection Agency (EPA) assigns regulatory definitions to animal feeding operations (AFOs) based on the size and density of livestock and the time those animals spend in confinement. By EPA definition, an AFO is a lot or facility where animals are kept confined and fed for 45 or more days per year, and where crops, vegetation, or forage growth are not sustained over a normal growing period.[41] A concentrated animal feeding operation (CAFO) is an AFO that has 1,000 or more animal equivalent units (AEUs) (see **Table IN.1** for hog size requirements) and, due to its size, must meet certain reporting requirements for point-source pollution into waterways.[41] As of 2008, any size AFO or CAFO that discharges or proposes to discharge waste directly into a waterway is required to apply for federal discharge permits.[42] AFOs are not regulated for airborne emissions nor are they required to submit environmental impact assessments.

To reduce potential environmental impacts from liquid and solid waste, land-application Nutrient Management Plans (NMPs) are created and filed by CAFOs, Concentrated Animal Operations (CAOs), and voluntarily by operations with local County Conservation Districts. While these written plans include the testing of soils and the calculation of nutrients (*e.g.,* nitrogen and phosphorus) needed for proper crop growth, and they record the amount of manure the soil can absorb and the amount that may be applied to fields,[43,44] the plans do not cover airborne contamination or mitigation.[45] State regulatory agencies report substantial barriers to responding to public health concerns from polluting industrial food animal production (IFAP) facilities, including lack of public health expertise within their office staff and limited financial resources.[46]

The lack of accountability and public health protection presents a large problem,[45] as food animals can produce many times more waste than humans [USDA Agricultural Waste Management Handbook, 2012]. A recent estimate of the amount of waste produced by the 9.5 million hogs in North Carolina is 10 billion gallons per year.[38] Further, CAFO manure contains a variety of potential contaminants, including nitrogen and phosphorus (causing algal blooms in waterways), *Escherichia coli*, unmetabolized hormones, antibiotics, and chemicals, as well as dead animals and animal blood.[42] Land-applied hog waste in particular can exceed federal guidelines for microbial loads in recreational water.[47] However, as mentioned above, state and federal reporting and monitoring requirements cover only the largest classification of CAFOs, and most AFOs have been exempted from airborne hazardous waste release reporting requirements even though many airborne toxic substances are present on IHOs (*e.g.,* ammonia, hydrogen sulfide, and volatile organic compounds). In 2013, researchers who attempted to gather toxic release reports found a dearth of information (0 received from 2,790 permitted North Carolina AFOs).[48]

AFOs and AFO manure-applied fields also contain a high concentration of bacteria and bacterial genes. Food animals may excrete active forms of antimicrobial drugs they are fed for production purposes (*i.e.,* growth promotion, disease prevention, and treatment) and, unlike human waste, animal waste is not treated to remove or inactivate pathogens. It does not enter a waste treatment facility; instead, it is often held on IHOs in lagoons to evaporate some liquid and then land-applied. This land-application process creates concentrated bacteria and antimicrobials at levels millions of times higher than at sewage sites.[49]

CAFO exposures as occupational hazards: A focus on respiratory health

With factory-like exposures to repetitive motions, heat and cold, animal antibiotics, microbes, cleaning chemicals, deceased animals, and feces, CAFOs carry a myriad of occupational risks. Of particular concern to our research team is the hazard industrial hog operations (IHOs) pose to the respiratory health of workers who perform day-to-day intensive animal production job tasks.[50] They may experience numerous exposures inside barns including, particulate matter (PM),[51,52] ammonia and carbon dioxide,[53] hydrogen sulfide,[54,55] methane, animal dander, cleaning chemicals,[56] endotoxin,[53,54,57,58] microbes,[53,54,59-61] and fungi,[59] and outside of barns as these particulates are pumped out by large industrial fans and through land application (*i.e.,* spray) of liquid waste.

IHO worker respiratory disease is well documented in the literature and includes, but is not limited to, rhinitis, sinusitis, mucus membrane inflammation syndrome, chronic bronchitis, chronic obstructive pulmonary disease (COPD), hypersensitivity pneumonitis, organic dust toxic syndrome, asthma-like syndrome and exacerbation of asthma. Inflammation from the presence of dust, dander, endotoxin, and gases increases the immune response in those exposed to IHO air. This inflammation is induced by an increased number of neutrophils[62,63] and diminished function of macrophages,[50] but increased phagocytosis of dust particles by macrophages.[51] There appears to be a physical tolerance to these airborne contaminants, with naïve IHO workers exhibiting more inflammation that those who have been previously exposed.[17]

A high prevalence of *S. aureus* nasal carriage has been documented in livestock workers, with an estimated 45% colonized with *S. aureus*.[64] The nares are an ideal area for the growth of *S. aureus*, which thrive in oxygen-rich conditions at 37°C with a pH of 6-7.[65] *S. aureus* does not grow well in the presence of a competitive flora because of acidification and nutritional competition.[65] *S. aureus* is known to reduce the number of commensal bacteria in the nares.[66] An imbalanced microbiome lacking commensals may lead to an inability to ward off dangerous pathogens leading to disease. Additionally, LA-MRSA strains, transmitted from farm animals to humans, may be transmitted further into the community.

While many species of animals may be colonized with *S. aureus*, recently methicillin-resistant *S. aureus* (MRSA) strains were isolated from several food animals.[65,67,68] In the Netherlands, contact with pigs is now recognized as a risk factor for *S. aureus* and MRSA carriage,[65,69] with swine workers showing higher rates of respiratory disease than other food animal workers.[25] One study found that individuals with current swine exposure were significantly more likely to carry *S. aureus* (prevalence ratio (PR):1.8; 95% confidence interval (CI), 1.4–2.2) and six times more likely to carry multidrug-resistant *S. aureus* (MDRSA) than those without exposure.[70] Further, in IHOs administering antibiotics versus those who did not routinely give antibiotics to healthy animals, significantly lowered rates of livestock-associated MRSA (LA-MRSA) and LA-MDRSA were found.[71]

While respiratory health impacts are often noted, the risk attributable to each constituent component of airborne contaminants has not been apportioned,[13,72] nor has the risk from each on-IHO work activity been fully detailed. This is a serious problem for the 31,500 reported IHO workers in 2,355 establishments within the United States.[35]

Asthma is increasing in the U.S.

Our understanding of asthma among those who live near and work at IHOs has greatly advanced in recent years. While some other IHO-induced diseases (*e.g.,* organic dust toxic syndrome) have been well defined for decades,[73] researchers still grapple with the confounding relationship between asthma and farming. For example, in Europe, exposure to farms has been shown to be protective of childhood asthma, while in the U.S. exposure to IHOs has been shown to increase childhood and occupational adult asthma.[30] Since most childhood asthma is allergic asthma, early-life immune education is an important mechanism in this pathway.

Asthma is a common chronic airway disorder present in 8% of the U.S. population[74,75] and is characterized by periods of reversible airflow obstruction. It is not clear how to prevent incident asthma and there is no known cure, only management of symptoms and pathways of airway inflammation.[74] It is caused by inflammation and airway hyper-reactivity and induced by exogenous exposures such as PM and microbial components, including *Staphylococcus aureus*.[76,77] One study found that 44% of children who lived on farms with swine were asthmatic, and this proportion increased to 56% if the swine were also given antibiotics in their feed.[78]

Asthma prevalence in the U.S. has increased, from 7.3% in 2001 to 8.4% in 2010, a percentage that now includes 18.7 million adults and 7.0 million children (aged 0-17 years).[74] Barnett and Nurmagambetov (2011) estimate that in the mid-2000s the total estimated cost of asthma to society was $56 billion, with productivity losses due to morbidity accounting for $3.8 billion and productivity losses due to mortality accounting for $2.1 billion.[79] While much research focuses on asthma in children, asthma continues to be a significant disease in adults as well.[80,81]

AFOs are increasing in the U.S. and around the world

Meat consumption is also increasing in the U.S.,[82] and the percentage of meat produced on AFOs is growing as well.[83] According to the United States Department of Agriculture (USDA), since 1994 large IHOs (those with over 5,000 head of pigs) have increased dramatically in size and efficiency. In 1994, only 27 percent of pigs were raised on IHOs, by 2014, that amount grew to 93 percent. Breeding pigs have more piglets and these piglets now take less time to reach market weight than before industrialization. Profits have also increased with this model, with U.S. pig producers receiving ~$10 billion *more* in gross income during 2014 ($16.1 billion) than in 2008 ($26.5 billion).[84]

As developing nations adopt the CAFO model of food animal production IHO exposure will inevitably become an even larger and more widespread problem. Traditionally, as countries become more developed and wealthier their citizens begin to eat more meat. We are seeing that this meat will largely come from AFOs. This may lead to more respiratory health impacts on more people in the U.S. and around the world.

An example of this phenomenon is found in China, where consumption of pork has increased markedly in recent years. Pingali (2007) describes how Asian diets are becoming more animal protein heavy, while reliance on rice is decreasing.[85] Chinese-held Shuanghui International Holdings acquired the world's largest pork producer, U.S.-based Smithfield, in 2013 and pork production *within* China continues to rise. While inconsistencies in production and consumption figures are noted, it is generally accepted that the number of small backyard Chinese pig farms is decreasing, the industrial model is taking hold, and pork is increasing as a staple food in China.[86,87]

CAFOs as a community health hazard: A focus on respiratory health

CAFOs are known to impact the health of the communities in which they are located.[42] Air emissions from IFAP houses through plume drift, via industrial-sized fans, and lagoon slurry spreading include hydrogen sulfide,[88-90] ammonia, endotoxin,[53] carbon dioxide, and Gram-positive microbes including *S. aureus*.[59,60,91] In addition, antibiotic-resistant *S. aureus* bacteria have been found in higher concentrations downwind of IHOs than upwind, and when pigs are in barns versus when barns are empty.[59]

Although it has been known as a cause of pneumonia since 1918, *S. aureus* respiratory impact is not well characterized in the general population or communities surrounding IHOs. Methicillin-susceptible *S. aureus* (MSSA), methicillin-resistant *S. aureus* (MRSA), and multi-drug resistant *S. aureus* (MDRSA) strains cause roughly 300,000 infections and 18,000 deaths annually in the U.S,[92] with a recent rise in community-associated MRSA (CA-MRSA) and in strains associated with livestock production.[93-95] While in the general U.S. population 1 in 3 are colonized with *S. aureus* (an upper respiratory opportunistic pathogen) and 1 in 50 carry MRSA,[92] colonization does not always lead to infection or other *S. aureus*-related disease, posing a conundrum for researchers.

In the Netherlands and Denmark, livestock-associated *S. aureus* (Clonal Complex 398) is now responsible for more than 40% of community- and hospital-onset *S. aureus* infections.[96,97] Therefore, public health researchers, community activists, and litigation teams place large importance on understanding IHO impacts on respiratory health for managing interventions on-IHO and in the community.

Odors released from facilities prevent residents from using outdoor space, turning on air conditioning units, hanging laundry outside, and opening windows; they decrease property values.[98,99] Community members assert that they are unable to use their property since IHOs were placed nearby and that pig waste was reaching their property as airborne IHO emissions. This claim can be investigated by the measurement of airborne *Staphylococcus aureus* and a hog-waste source tracking marker known as Pig-2-bac (a swine-specific *Bacteroidales*).[100,101]

In addition to a nuisance, these emissions also cause physical and psychological effects, with respiratory symptoms comparable to those reported in IHO workers.[102] Researchers have found associations between increased odor from hog facilities and increased blood pressure in residents,[103] neurobehavioral and pulmonary functions diminished in IHO neighbors,[104] and increases in childhood asthma symptoms,[6,76] increased stress and negative mood,[105] diminished memory and increased nausea,[106] and higher odds of stomach ache,[107] as well as an increase in all-cause and infant mortality compared to those without an IHO nearby.[12] These impacts are greatest in minority and low socioeconomic status (SES) communities, creating a demonstrated environmental justice issue in North Carolina and other CAFO-dense states.[108-110]

Studies with objective measures of respiratory responses in IHO workers are needed

Farm workers are known to experience a high burden of occupational airway disease, but few studies have examined the dynamics of respiratory health within the context of IHO workers' burden of disease. Previous studies suggest that respiratory disease in IHO workers is related to chemical (*e.g.,* ammonia, hydrogen sulfide, carbon monoxide) and bioaerosol (*e.g.,* organic toxic dusts, PM, endotoxin) components of air inside animal confinements.[56,111] The majority of these studies, however, derive conclusions from pulmonology studies of farming students, non-IHO workers, owner-operators of farms, and workers outside the IHO industry, with a strong emphasis on pesticide application and male-only recruitment.[112] Lack of lung function measures from the day-to-day workers representative of the IHO workforce, coupled with a myriad of exposure activities, limits the inferences that can be made for populations that might be performing high-exposure job tasks on-IHO.

Studies of personal protective equipment in the context of IHOs are needed

The U.S. National Institute for Occupational Safety and Health (NIOSH) has developed a hierarchy of controls ranging from most effective protections for workers on the job to least effective. In order of effectiveness they are: *elimination* (*e.g.,* dismantling IHOs), *substitution* (*e.g.*, producing a food animal with lower respiratory risk to workers), *engineering controls* (*e.g.*, automate job tasks to keep workers out of barns and away from animals), *administrative controls* (*e.g.*, change or rotate job tasks), and *personal protective equipment* (PPE – *e.g.,* masks and eye protection).[113] While elimination and substitution are preferred by NIOSH, they are not in line with all current community wants or needs. Further, calls for workplace air standards[114] have not been met.

While low adoption of respiratory protection among animal confinement workers has previously been reported,[115] the use of face masks specifically in an IHO context has been shown to reduce the amount of LA-*S. aureus* recovered from the nares of IHO workers.[116] A longitudinal PPE educational study from Iowa found that over the course of 5 years follow up, those in the intervention group reported more PPE use and less symptoms of organic toxic dust syndrome.[117] However, it remains unclear whether there are job tasks for which it is particularly important for workers to don a face mask in order to reduce exposures to not only microbes, dusts, and gases and thus protect respiratory health. It is also not known whether employers are providing masks, what type are being used, or whether training in their use is provided.

While various types of gear are available on the market, neither NIOSH nor any other governing body has recommended what workers should wear. No agency offers guidance on whether the use (and discomfort and cost) of a full-face respirator is warranted or a relatively comfortable and less expensive N95 mask would suffice to eliminate risk.

By conducting an analysis of how IHO work activities and practices are related to better or worse health outcomes, this knowledge may inform policy changes in IHO practices and/or working conditions and inform workers on how they can protect their own respiratory health using PPE.

This study represents a shift in IHO workplace exposure research: Use of fixed-effects regression, citizen scientist trainings, and community-driven data collection

Of the literature regarding IHOs and respiratory health, very few studies use fixed-effects regression techniques to control for an array of unmeasurable confounders that results from a lack of access to collect data on-site at IHOs. This statistical method (expanded upon in the **Detailed Methods** section) allows individuals to serve as their own controls, instead of comparing workers to other workers or workers to community members. This statistical tool also eliminates the need to input time-invariant confounders into models as they cannot induce bias. These confounders include not only participant characteristics (*e.g.,* age, sex, race/ethnicity) but also on-IHO factors such as barn structures,[118] lagoon locations, and spray field proximity that do not vary or change over time during the period of data collection. Without the use of fixed-effects regression, residual confounding due to such time invariant characteristics may occur – and may be present in prior work. This method gives greater confidence in the observed statistical associations, as IHO access was not possible and therefore none of the analyses are informed by IHO facility characteristics, on-site air sampling, personal monitoring, or work activity monitoring.

Few U.S. studies have been conducted about the relation between IHO work activities and impacts on respiratory health. Most are cross-sectional; even fewer have evaluated the acute time-varying dynamics of livestock work exposures and respiratory outcomes.

Further, most studies have examined cohorts of white male owner-operators, not the largely Hispanic groups of workers who spend their day-to-day work life inside IHO confinement buildings. A large hindrance to accessing this population of non-owners is fear of job loss / termination. By partnering with a long-standing community group, the Rural Empowerment Association for Community Help (REACH), researchers and community partners are better able to engage with, recruit and retain a non-owner IHO worker cohort to examine the impacts of IHOs work activities on their physical and respiratory health. In a second and pilot investigation, building from the first larger longitudinal study, investigators and community partners were able to recruit additional IHO workers, community residents, and their children. A vast majority of data collection for both studies was conducted by REACH, which is continuing to build capacity for future research to aid the community.

Understanding risk factors of IHO worker and community respiratory disease is key to reducing the burden

The means to control and prevent asthma and other respiratory diseases are predicated on understanding their causes. Workers and employers must be better informed about how personal protective equipment (PPE) and other control measures on-IHO can protect respiratory health. Academics and community members wish to better understand how IHOs impact health and how bacteria, gases, and other irritants are spread off-operation, especially in areas of intense production. It is critical to study the recent emergence of and potential for dissemination of livestock-associated *S. aureus* in populations that have pig contact and live in high-density pig production regions. This dissertation provides a greater understanding of the role IHOs play in the respiratory health of IHO workers and it lays the framework for conducting studies with those in nearby communities.

TABLES

Table IN1.1. Type of animal and animal unit that designates industrial food animal production (IFAP) as an animal feeding operation (AFO) or concentrated animal feeding operation (CAFO).[119]

Animal	**AFO** A lot or facility where animals are kept confined and fed or maintained for 45 or more days per year, and crops, vegetation, or forage growth are not sustained over a normal growing period.		
	"Small CAFO" Confines the number of animals listed and has been designated as a significant contributor of pollutants.	**"Medium CAFO"** Falls within the size range below and manure or animals come into contact with surface water that passes through the IFAP.	**CAFO** Confines at least 1,000 AEUs or the number of animals described below.
Cattle, N			
Cow/calf pairs	<300	300 – 999	≥1,000
Dairy	<200	200 – 699	≥700
Chicken, N			
Broiler or laying hens[1]	<9,000	9,000 – 29,999	≥30,000
Broiler[2]	<37,500	37,500 – 124,999	≥125,000
Laying hens[2]	<25,000	25,000 – 81,999	≥82,000
Ducks, N			
Ducks[1]	<1,500	1,500 – 4,999	≥5,000
Ducks[2]	<10,000	10,000 – 29,999	≥30,000
Hogs, N			
<55 pounds	<3,000	3,000 – 9,999	≥10,000
>55 pounds	<750	750 – 2,499	≥2,500
Horses, N	<150	150 – 499	≥500
Sheep or lambs, N	<3,000	3,000 – 9,999	≥10,000
Turkeys, N	<16,500	16,500 – 54,999	≥55,000
Veal calves, N	<300	300 – 999	≥1,000

[1]For those IFAPs with a liquid manure handling system.
[2]For those without a liquid manure handling system.

DETAILED METHODS

Overview

In this chapter methods critical for the work and not found in full detail elsewhere in the dissertation are featured. In brief, data sources, variable choices, and overall data analysis is covered. Within the data analysis section, greater detail regarding fixed-effects models is presented, as this is a more recent data analysis tool and less well-known to the greater research community.

Data sources

Data for this dissertation was collected in concert with community members of the REACH organization, located in Warsaw, N.C. Nested in a larger analysis, the data regarding workers comes from a 16-week longitudinal data set that included children of IHO workers.

Chapter 1

Survey data collection was carried out on paper forms by REACH community organizers, many of whom were both English- and fluent Spanish-speakers.

Chapter 2

Data for this chapter comes from the same source as Chapter 1 and additionally includes spirometry data. This data was collected from an investigator who was NIOSH-certified in performance of spirometry

(Dr. Christopher D. Heaney) who conducted spirometry testing using the Koko spirometer and trained community researchers in performance of spirometry with the

Piko-1 device. The community researchers performed spirometry with the Piko-1 at enrollment and at each subsequent visit.

Chapter 3

From a dataset tangential to Chapters 1 and 2, Chapter 3 data comes from a Johns Hopkins Institutional Review Board (IRB)-approved add-on study to the previously mentioned 4-month-long cohort.

Data analysis

Review of Logistic and Linear Regression Models: Between-person variation

Logistic and linear models were employed in baseline analyses to assess exposure and outcome relationships in regard to a "grand mean," or averages of individuals. As seen in **Equation 1**, the estimate of a continuous outcome for an individual (*i*) or average set of individuals can be represented at one or more time points (*t*), with average fixed errors (ε) and average time-varying errors (α).

$$E\,[Y_{it}] = \beta_0 + \beta_{it}x_{it} + \varepsilon_{it} + \alpha_{it} \tag{1}$$

This model can be expressed as a multiple linear regression model (**Equation 2**) with the addition of covariates to adjust for potential confounding factors that may exist between persons (*e.g.,* age, sex, race/ethnicity).

$$E\,[Y_{it}] = \beta_0 + \beta_{it}x_{it} + \beta_{it}age_{it} + \beta_{it}sex_{it} + \beta_{it}race_{it} + \varepsilon_{it} + \alpha_{it} \tag{2}$$

Logistic (binary outcomes) and linear (continuous outcomes) models are useful to model cross-sectional data. If longitudinal data is to be analyzed using these statistical tools, one must account for the clustering of observations within person over time.

Fixed-Effects Regression: Within person variation

In comparison to logistic and linear models looking at an overall average, or grand mean, fixed-effects analyses [fully described in Allison, 2009] compare persons to themselves through subtraction. The comparison to one's self by using a difference between time points eliminates the need to add time-*invariant* confounders into the model (*e.g.,* age, sex, race/ethnicity). In fact, if one *does* include these factors in a fixed-effects model, they fall out, not contributing in a meaningful way to any point estimate (**Equation 3**).

$$
\begin{aligned}
& E\,[Y_{11}] = ß_0 + ß_{11}x_{11} + ß_{11}age_{11} + ß_{11}sex_{11} + ß_{11}race_{11} + \varepsilon_{11} + \alpha_{11} \\
- \; & \underline{E\,[Y_{12}] = ß_0 + ß_{12}x_{12} + ß_{11}age_{11} + ß_{11}sex_{11} + ß_{12}race_{11} + \varepsilon_{12} + \alpha_{11}} \\
& E\,[Y_1] = ß_1x_1 + \varepsilon_1
\end{aligned}
\tag{3}
$$

Using this methodology, person-specific means and express all variables as deviations from those per-person means are created.

Since this tool compares person to self, it necessitates longitudinal data. It also necessitates the same measurement be taken for an individual on two separate occasions, and that these measurements differ. For these reasons baseline and follow-up analyses are presented separately throughout this dissertation. The two surveys employed for Chapters 1 and 2 employed questions aimed at different hypotheses: (a) that chronic exposures lead to chronic health effects (baseline survey) and (b) that time-varying exposures induce time-varying health impacts (follow-up survey). Only in the follow-up questionnaires are fixed-effects analyses able to be used.

While fixed-effects models are not subject to confounding by time-invariant characteristics, they can be confounded by time-varying ones. These can – and should –

be added into models when needed to control for confounding. For example, in Chapter 2, spirometry measurements were taken by different interviewers at different times during the day. While a model of the association between PPE use in the past week (*i.e.,* exposure) and FEV_1 value (*i.e.,* outcome) would not need to be adjusted for sex of the participant (an underlying, fixed characteristic), interviewer (coded as a dummy variable) was adjusted for, as some interviewers appeared to be better coaches. Likewise, the hour when the test was administered was also included in fully-adjusted models, as literature shows there is a diurnal change in lung function.

Without the utilization of this tool the estimates in Chapters 1 and 2 may have been severely confounded. This fact arises from the inability to measure a vast number of on-IHO exposures. Even had access to the IHOs been given, the sheer number of differences between operations may have been insurmountable.

The main drawback of fixed-effects analyses is the loss of observations if no changes in outcome measurements occur. Analyses in Chapter 1 suffer from this more than in Chapter 2, as Chapter 1 relies on binary measures and scores; in Chapter 2, spirometry outcomes are continuous. Even the slightest change in a continuous measurement will keep the visit in the model, while scores of the same value are dropped, thus dropping that visit (although not necessarily that person) from the model. This variation in persons and records is one reason the number of persons and observations is presented in each table.

Another drawback to fixed-effects models is that by using only this method researchers fail to gain insight into the impact of fixed characteristics on outcomes or exposure-outcome relationships. In addition to the differences in question wording, this is a second reason separate baseline and longitudinal analyses were performed.

A final drawback is that *p*-values, standard errors, and confidence intervals are often wider in fixed-effects models than traditional random effects approaches. This can result from wide variation in estimates between people (which are disregarded in fixed-effects models) and small variation in differences in measurements within an individual.

Generalized estimating equations: Justification for not using GEEs

The rationale behind not using generalized estimating equations (GEEs)[120] that can provide between- and within-person variation point estimates is three-fold:

1. This study was conceived with the notion of using fixed-effects and was thus powered for these analyses.
2. There is a lack of on-IHO measurements to adequately control for confounding between persons. Therefore, between-person estimates are inherently biased and must be disregarded.
3. These are analyses that have not been performed before to answer these exposure-outcome questions within this population. While replication of previous results in new populations, in new locations, in new eras is important to build to the body of evidence of the impact IHOs have on human health, it is also important to analyze data in different fashions to see if the results align.

Model Diagnostics

Co-linearity

To assess co-linearity, two-by-two tables and Pearson chi-squared tests were used.

Missingness

Due to a small percentage of missingness and missingness not at random (MNAR), no imputation was carried out in this work.

For scores, if any of the variables that composed the score were missing, the entire score was treated as missing. Missingness was handled in this fashion to reduce the bias associated with possible over-counting of cases in relation to non-cases. For example, in Chapter 1, heat and dustiness score (**Table 1.7**) was created. This score consisted of unweighted, binary summations of responses to ambient barn conditions:

Hot temperature (yes=1, no=0)

Extreme malodor (yes=1, no=0)

Extreme dust (yes=1, no=0)

Vents off (yes=1, no=0)

New herd entering the barn(s) (yes=1, no=0)

A participant report of "yes" to hot temperature and extreme dust but "no" to the others would be coded as a score of 2. A participant who failed to provide answers to the other questions would be coded as missing.

In binary analyses, this same method was followed. For example, in the subsequent table in Chapter 1 (**Table 1.8**), the first binary exposure of interest is

Experienced any heat or dustiness. A respondent who answered “yes” to hot temperature and extreme dust but “no” to the others would be coded as exposed, or 1. However, a respondent who failed to provide answers to the other questions would be coded as missing. One might argue that since a respondent who reported exposure should be coded as a 1, even in the face of missing responses, but had respondents answered “no” to some and failed to answer others, we might have inadvertently classified them as unexposed (*i.e.,* 0) when they actually were exposed (*i.e.,* 1). This leads to a discrepancy between how persons are treated. It was therefore decided to handle each respondent equally, even if this led to a reduced sample size.

CHAPTER 1

Work activities, mucus membrane symptoms, and respiratory health outcomes among industrial hog operation workers, North Carolina, USA

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ABSTRACT

Background: Respiratory disease among industrial hog operation (IHO) workers is well documented; however, it remains unclear whether specific work activities might be well-suited for future interventions to reduce adverse exposure.

Objectives: To assess the relationship between typical (time-invariant) and transient (time-variant) IHO work activities and personal protective equipment (PPE) use with self-reported mucus membrane and respiratory health outcomes within a cohort of IHO workers.

Methods: 103 IHO workers who completed a baseline and up to eight bi-weekly (*i.e.*, every two weeks) study visits were enrolled. IHO workers reported typical (baseline) and transient (bi-weekly) work activities, PPE use, and physical health symptoms during each study visit. At baseline, symptoms examined included those effecting the eye, nose, and throat, allergies, and doctor-diagnosed asthma. Longitudinally, respiratory symptoms, symptoms that interfere with sleep, sneezing, headache, and eye and nose irritation were examined. Baseline and longitudinal associations between work activities and health outcomes were investigated using generalized logistic models and participant-conditional fixed-effects logistic regression models, respectively.

Results: At baseline, reports of ever *vs.* never drawing pig blood, applying pesticides, and increasing years worked at any IHO were positively associated with reports of mucus membrane irritation (eye, nose, and/or throat) symptoms. Working, on average, seven days per week (*vs*. less than seven days per week) was associated with decreased reports of eye, nose, and/or throat symptoms, any allergies, and asthma, a potential indication of healthy worker effect bias. Over time, transient exposures, including those associated with dustiness in barns, cleaning of barns, and pig contact were associated with increased odds of a variety of symptoms, particularly in the highest categories of exposure. Those who used *vs.* did not use PPE had decreased odds of symptoms interfering with sleep (OR: 0.08; 95% CI: 0.01, 0.84) and eye or nose irritation (OR: 0.14; 95% CI: 0.02, 0.88). And those who washed their hands more *vs.* less frequently (≥ median *vs*. < median) had decreased odds of any respiratory symptom (OR: 0.32; 95% CI: 0.12, 0.83).

Conclusions: In this healthy volunteer IHO worker population, typical and transient work activities were associated with self-reported mucus membrane and respiratory health outcomes. Consistent PPE use and handwashing warrant further investigation as potential protective interventions to reduce adverse exposures.

INTRODUCTION

Industrial hog operations (IHOs) pose an occupational respiratory health risk[16,50,121,122] driven by bacteria, viruses, dander, gases, and feed constituents. Particulates become airborne from activities of workers and animals within animal housing facilities[123,124] and contribute to exposures that drive respiratory outcomes. However, the riskiest activities have yet to be fully apportioned, and transient symptoms (*i.e.*, acute and sub-acute) are not well described. Most studies examining IHO work exposures are decades old, and protective measures have not been fully evaluated. Further, studies that have followed participants over time have done so typically in the long term, with significant time (*i.e.*, years) between data collection,[125,126] or same-day pre- and post-shift,[26,27] a timescale that is perhaps too brief to capture short-term health changes. This gap seriously limits the ability to propose regulatory mandates for health protections among the estimated 33,000 industrial hog operation (IHO) workers in the U.S.[35]

Leaders in the field have advocated for improvements in exposure assessment and the investigation of a broad range of disease outcomes.[127] Data regarding health risks to U.S. agricultural workers comes largely from the Agricultural Health Study, a prospective cohort of over 89,000 North Carolinian and Iowan licensed pesticide applicators and their spouses. This study, initially conceived to examine incident cancer outcomes related to pesticide exposures,[128] does not focus specifically on industrial hog workers, does not capture all farming activities, and focuses disproportionately on operation managers rather than those who work day-to-day inside concentrated animal feeding operation (CAFO) barns.

A leading research group in Iowa also attempted to quantify health outcomes in swine workers, creating one of the longest (5 years with three follow up visits annually) and largest cohort studies, enrolling 2,059 hog operations.[129] From this total, 40 were CAFOs (at least 5,000 head operations) with 207 IHO workers enrolled, as well as 158 non-confinement hog workers for comparison. Of the 207 IHO workers, 100 percent were white, 88 percent were male, and 20 percent were smokers. Researchers reported that participants who worked in IHOs compared to non-confinement operations had more chronic and acute (measured after two hours at work) respiratory health symptoms, but fewer reports of muscle or joint pain.[129] This study benefitted from on-operation access to collect air samples while workers worked and inside their masks, but unfortunately, enrollment for this study began in 1986, and IHO work practices as well as the demographics have changed from those in this decades-old research. Further, investigators did not collect data regarding the work activities.

Data from this cohort also showed that IHO workers were willing to become educated in personal protection and documented that they found value in learning about methods to protect themselves from exposures,[130] and other cohorts has shown that exposure to pesticides and other respiratory irritants can be modified by the use of personal protective equipment (PPE).[131] In particular, N95 masks have been shown to block harmful pathogens found on IHOs.[132] Nevertheless, in 2010 an expert panel concluded that researchers do not entirely understand which IHO workers could benefit most from the use of PPE[34] and the panel was unable to determine whether PPE use for specific tasks is sufficient or whether PPE should be donned as soon as a worker steps on-IHO.

An additional complication, particularly for U.S.-based studies, is the frequent disconnect between assessment of CAFO exposure and measurement of worker outcomes, since on-operation access is rarely granted. Therefore, many studies comparing workers to each other may suffer from residual confounding due to differences in exposure, barn construction,[133] and activities between operations. Application of fixed-effects regression analyses, which compares workers to themselves over time, can be used to examine exposure-outcome relationships and mitigate some of the threats to inference from heterogeneity in IHO site exposures. This technique has been successfully employed by Schinasi *et al.*[23] who found strong associations with decrements in community health and increasing CAFO odors.

To the best of our knowledge, no prior U.S. study has looked at self-reported work activities, personal protective equipment (PPE) use, and self-reported health outcomes among IHOs workers who perform the day-to-day operations on industrial facilities. The purpose of this paper is to identify factors that are causally associated with the diminished respiratory health of the IHO workers we surveyed and to provide insight into factors for future research and interventions, using an underemployed biostatistical method.

METHODS

Study population

The study population included a total of 103 industrial hog operation (IHO) workers from the top 10 hog producing counties in North Carolina. Detailed methods on enrollment have been previously described.[134] In brief, they are as follows: Participants were recruited and enrolled on a rolling basis from October 2013 to February 2014, with the last sampling date in June 2014. Participants were eligible for inclusion in the sample population if they were: (1) current IHO workers (full- or part-time) and (2) agreed to participate in the study. Eligibility for inclusion in the baseline analysis population required that they provide survey data for the baseline enrollment visit. IHO workers were eligible for inclusion in the longitudinal analysis population if they were enrolled in the study and completed at least one follow-up visit. Signed informed consent was obtained from each participant prior to participation. The study protocol was approved by the Johns Hopkins Bloomberg School of Public Health Institutional Review Board.

Study location

In 2017, it was reported that North Carolina contained 10.1% of all pigs and hog operations in the U.S., employing ~3,300 workers (NAICS code 1122),[35] with most of this activity in the southeastern portion of the state. Located in southeast N.C., Duplin County is the second-greatest pork producing county in the U.S.[83] It is also home to the Rural Empowerment Association for Community Help (REACH), who performed the recruitment, enrollment, and much of the data collection for this analysis.

Questionnaire

At baseline, participants responded to survey questions consisting of how both health and job tasks and environment were “typically” or “usually” at their current IHO of employment. This questionnaire was designed to capture established work routines and health symptoms. For example, participants were asked, “As part of your work, do you ever give antibiotics to pigs?” and “Do you usually bring up phlegm (mucous) [sic] from your chest?” Information about, and proxies for, the frequency, magnitude, and duration of participants' contact with livestock, PPE use, and animal species and life stage, typical job activities, as well as contact with livestock manure and the dustiness of barns was collected.

At each of eight follow-up study visits, a second questionnaire adapted from the Agricultural Health Study, the American Thoracic Society,[135] and Kimbell-Dunn *et al.*[136] was administered to collect information regarding work practices and health symptoms. The follow-up questionnaire was designed to capture transient exposures and symptoms. At each follow-up study visit information about the frequency, magnitude, and duration of participants' contact with pigs, job activities, personal behaviors (*e.g.*, cigarette use), and PPE use at work was collected. Each question asked participants about the week prior to the study visit. For example, “In the past week have you…” In both questionnaires, with an attempt to capture a dose-response relationship, some questions asked participants to rate exposure using a Likert-like scale while others asked for binary (ever/never or yes/no) responses.

Statistical analysis

At baseline, generalized logistic models clustered for household were used to assess the relationship between self-reported exposures and outcomes. Outliers with biologically-implausible values were dropped. Due to collinearity, persons reporting eye, nose, and throat symptoms were grouped as cases, and those who reported none of the three symptoms were classified as not having case status. Also due to collinearity, those who reported ever giving pigs shots and/or antibiotics were grouped together. Due to the small number of reported outcomes in some categories, analyses on exposures and outcomes with fewer than 5% of respondents indicating case status were not run.

Covariates explored in baseline logistic exposure-outcome analyses included baseline age (a continuous variable in years), sex (binary male/female), and race/ethnicity (binary non-black Hispanic/other), asthma medication use for relevant analyses (binary controlled/uncontrolled), current smoking status (binary smoker/non-smoker), and season (summer, fall, winter, spring),[18] as well as days since last work shift (continuous). Based on prior knowledge and model fit, age and sex were included as baseline confounders (**Table S1.1)**. Crude models are presented as main tables in this analysis due to convergence issues in adjusted models and the consistency between point estimates in crude and adjusted regressions. In alternative sensitivity analyses (not shown) prevalence odds ratios were calculated and showed to overestimate the exposure-response association. Due to this, prevalence ratios (PRs) are presented for baseline analyses.

Longitudinal data were also checked for accuracy and variability. Exposures or outcomes with limited variability (less than 10 cases reported over the 752 study visits) were *a priori* dropped from analyses to reduce any bias associated with small numbers (**Tables S1.2a and S1.2b**). Due to multi-collinearity (assessed via χ^2 tests, with an α cutoff of 0.05) reports of extreme temperature (3 or 4 of a 0 to 4 Likert-like scale), extreme malodor (3 or 4 of a 0 to 4 Likert-like scale), extreme dust (3 or 4 of a 0 to 4 Likert-like scale), vent fans turned off or non-existent at the facility (binary yes/no), and/or a new herd entering the barns in the past week (binary yes/no) were coded as a 1, whereas persons who reported none of the aforementioned activities were coded as referent 0 in binary analyses. For trend analyses, binary forms of the input variables were summed. Using the same methodology, on-IHO use of chemicals, pesticides, pressure washing the inside of barns, and using a torch to clean the barns were also grouped into a cleaning activity score. In both the environmental barn conditions and cleaning activity scores, summations of scores equaling 4 were recoded as 3 due to small numbers (1 of 711 for dust and 12 of 738 for cleaning). Intense pig contact activities (giving pigs shots and/or medicine) were also grouped using the same process. The individual activities and exposures were summed to assess the health implication for persons performing none to all 10 of the activities.

The use of personal protective equipment (PPE -- any mask, eyewear, and full body suit/coveralls) was also grouped due to multi-collinearity. Participants were coded as a 1 in each stand-alone PPE category if they reported use of the specific PPE at least 80% of the time in the past week. These stand-alone values were summed with the possibility of reports of no PPE use to three types. Mask, eye protection, and coveralls were chosen for this analysis because we believed them to (1) be *a priori* related to the outcomes of interest and (2) have variability in their use at baseline and over time and thus would not be dropped from fixed-effects regression models. For example, 726 of 737 (98.5%) of reports of boot use were 100% in the past week; boot use was therefore not used in models. Reports of the number of times a person washed his/her hands was assessed in tertiles due to non-linearity. A report of handwashing 100 times per shift was dropped. Groupings were also created for adverse health outcomes *a priori* based on biological understanding and number of case reports.

In longitudinal analyses we used fixed-effects logistic regression to assess the relationship between self-reported exposures and outcomes in the past week, and to control for time-invariant confounding variables[137] such as differences in the physical production facilities and the operational structures (*i.e.*, types of feeders, how often pits under slatted floors are drained, etc.). Confounders of interest from the literature and relevant to fixed-effects analysis included month of visit.[123]

All data were analyzed using Stata (StataCorp. 2017. *Stata* Statistical Software: Release 15. College Station, TX: *StataCorp* LP).

RESULTS

At baseline, 103 workers entered the cohort through rolling admissions (enrolled in January/February or October/November). As reported in previous studies, these current IHO workers (with 1-27 years of IHO experience) were mostly non-black Hispanic (88%), male (55%), and aged 16-62 years.[116] In this cohort, 24 worked in feeder and/or finisher barns, while 46 worked exclusively in sow, nursery, and/or farrow barns.[116] Most did not live on the same property as an IHO (92%) (**Table 1.1**). This contrasts to prior work, where most of those included in the cohorts were white male farm supervisors and not people who worked day-to-day in the barn and in contact with swine.[128] In congruence with past studies, most were non-smokers (83%) and were not overweight (56%). About half (43%) of workers reported owning either a cat or dog (**Table 1.1**).

Typical occupational activities were reported, with 8 years working on any industrial hog operation (IHO), an average of 6.4 days per week, and a majority of time spent in direct contact with pigs (82% of time at work) (**Table 1.2**). The most prevalent work activities workers reported ever performing include handling dead pigs (79%), giving pigs shots or injections (69%), having direct contact with pig manure (67%), administering antibiotics (62%), applying pesticides in or around barns (49%), washing work clothes with the laundry of household members (16%), and drawing blood from pigs (9%). Participants were also asked to classify typical mask usage at work, and 38% responded that they always wore a mask (**Table 1.2**).

Participants were asked to classify whether they ever experienced a variety of symptoms, outside of having a cold or the flu, and of those ever (*vs.* never) reporting symptoms, if they experienced them within the last month. Respondents most frequently reported ever having eye irritation (18%), nose irritation (16%), throat irritation (15%), any allergies (13%), and asthma (9%). Of those who reported eye, nose, and throat symptoms, a majority reported having them within the past month (63%, 67%, and 87% respectively, **Table 1.3**).

At baseline, those who reported ever drawing pig blood had increased likelihood of eye, nose, and throat symptoms (PR: 3.67; 95% CI: 1.93, 6.95) and allergies (PR: 4.40; 95% CI: 1.67, 12). Statistically significant increased prevalence of eye, nose, or throat symptoms were also reported in those who ever applied pesticides in or around pig barns (PR: 2.19; 95% CI: 1.00, 4.80) and those who washed work clothes with household laundry (PR: 2.30; 95% CI: 1.00, 5.29). Across tertiles of years worked on any IHO, more eye, nose, and throat symptoms were reported (p for trend: 0.006), and in the uppermost tertile of exposure (PR: 4.29; 95% CI: 1.50, 12). This trend was also seen in the association between eye, nose, and throat symptoms and tertiles of percent of life worked on any IHO (p for trend: 0.042; highest tertile PR: 3.35; 95% CI: 0.99, 11).

In the unexpected direction, reports of always wearing all three protections (full body suit/coveralls, mask, and eye protection) on the job were associated with higher odds of reports of allergies (PR: 3.76; 95% CI: 1.43, 9.88), while working all seven days per week compared to those working less often was associated with lower odds of allergy reports (PR: 0.09; 95% CI: 0.01, 0.62) (**Table 1.4**). In models that converged, these associations were consistent in direction and magnitude after adjustment for age and sex (**Table S1.1**).

In longitudinal follow-up visits, 101 workers were retained past enrollment. Of the 101 persons eligible for data analysis, 95% of study visits were completed, and 90 of the 101 completed all eight follow-up visits (**Figure 1.1**). Multiple imputation was not conducted as, overall, very few data points were missing (~5-10% per analysis) and the missingness was determined to not be at random.

In reports of exposures in the previous week, persons reported work for 6±1 days per week, 42±12 hours worked per week, 38±14 hours in direct contact with pigs, 61±166 pigs sick per week, 42±120 dead pigs per week, and 54±46% of the time a mask was used at work. Administering shots was reported as a high-frequency activity (49%) in the past week, as was using cleaning chemical(s) (56%), pressure washing (39%), administering pigs medicine (32%), applying pesticides (30%), vent fans turned off or non-existent at the facility (24%), extreme malodor (24%), temperature in the barns being hot (14%), and extreme dust (4%) (**Table 1.5**).

Outcomes of high prevalence and variability reported in the same bi-weekly surveys included any respiratory health symptom (9%), consisting of excessive coughing (3%), runny nose (3%), difficulty breathing (2%), shortness of breath (1%), wheezing or whistling in chest (1%), and/or chest tightness (0%, 2 cases). Symptoms interfering with sleep were reported in 3% of surveys, and sneezing and headache in 2% of surveys.

Mucous membrane symptoms, consisting of burning, tearing, or irritated eyes (1%) and/or burning or irritated nose (1%), were reported in 2% of bi-weekly surveys (**Table 1.6**).

Time-varying acute health outcomes and work activities the week immediately preceding the bi-weekly study visit were also assessed (**Tables 1.7a and 1.7b**). Due to collinearity, individual exposure measures were combined into categories, as were adverse health outcomes. Using fixed-effects regression to control for time-invariant confounders, consistency was seen between activities on-IHO that produced or retained dust within barns, cleaning activities, and activities that involve close contact with pigs. In these categories the most profound effects were seen in the upper ends of exposure, with significant p-for trends ($p<0.05$) for many associations (11 of 25). While PPE use was not significant in any trend analyses, the use of PPE showed a directionally protective effect in almost all outcome groups (14 of 15). Due to the number of associations examined we did not adjust for multiple comparisons.

Drawing from the exposure scores in **Tables 1.7a and 1.7b**, exposures in a sensitivity analysis were modeled as binary exposed/unexposed (**Tables 1.8a and 1.8b)**. Consistency between the main and sensitivity analyses was observed, with higher odds of reporting health impacts and all exposures hypothesized to be detrimental to human health (*i.e.,* environmental barn conditions, cleaning activities, activities involving close contact with pigs, and performing two or three of the preceding activities). Also, as hypothesized, odds were in the protective direction for any PPE use (compared to those using none in the past week) and with those who washed their hands at least 8 times per shift (the median) in 4 of 5 outcomes (**Tables 1.8a and 1.8b**).

Binary-scored exposure activities and any respiratory symptoms in the past week were stratified by consistent mask usage (≥80%), consistent coverall usage (≥80%), and handwashing at or above the mean (average of at least 8 times per shift) over the course of the study and reported in **Table S1.4**. Regardless of protective action, all exposures resulted in increased odds of any respiratory symptoms. For those models where both strata converged, half (4 of 8) were in the expected direction. Of the two that were significant and in the unexpected direction, both showed higher odds of any respiratory symptoms in those who used full body suit/coveralls more consistently.

DISCUSSION

In this study of industrial hog operation (IHO) workers elevated odds of symptoms in workers who reported ever performing activities and those who performed transient exposure activities on the IHO were found. At baseline, reports of ever drawing pig blood, applying pesticides, and increasing years worked at any IHO were consistently associated with reports of eye, nose, or throat symptoms. Working, on average, seven days per week was associated with decreased reports of symptoms, a potential indication of healthy worker effect bias. Over time, acute exposures, including those associated with dustiness in barns, cleaning of barns, and pig contact, were associated with increased odds of a variety of symptoms, particularly in the highest categories of exposure. Those who wore PPE and washed their hands at or above the median had decreased odds of symptoms compared to those who did not wear PPE and who washed their hands less frequently. Conversely, and contrary to expectation, consistent coverall usage was associated with increased odds of acute respiratory infection, a possible case of reverse causation.

In congruence with the Agricultural Health Study,[128] this cohort is also made up of mostly non-smokers, however, a higher prevalence of self-reported asthma (8.7%) than was reported here than in the Agricultural Health Study (5.1%).[138] The prevalence of asthma in this predominantly non-black Hispanic adult population also was higher than national averages of non-black Hispanic adults (6.4%)[139] and higher than a prior longitudinal cohort (5.5%).[140] While capturing the development of asthma in our cohort was not possible, we did observe an increase in reported cases of asthma with increasing tertiles of years worked on any IHO (PR: 2.55; 95% CI: 1.03, 6.34), which is consistent with prior reports of increasing trends in development of asthma among farmers.[141]

In cases where we failed to find a statistically significant relationship (*e.g.,* **Table 1.4** reports of ever drawn pigs blood and asthma PR: 3.95; 95% CI: 0.81, 19.17) or one that goes in the opposite direction from underlying biologic knowledge (*e.g.,* **Table 1.8** reports of sneezing in the past two weeks and any cleaning activities in the past two weeks OR: 0.84; 95% CI: 0.22, 3.27) we offer these potential explanations: (1) healthy-worker effect bias; (2) not enough power (particularly for cross-sectional analyses); (3) imprecise reporting (*e.g.*, hours at work per week) distorting effect estimates; and (4) reverse causality. Underlying biological explanations do account for some associations that may at first appear in the un-hypothesized direction. For example, Bonlokke *et al*. observed that having time off from IHO work or using a respirator while on-IHO can actually be detrimental to worker respiratory health and the immune system due to loss of adaptation.[142]

While IHO workers were not queried directly on which masks were used, subsequent assessment of a small number of workers in a follow-up study (n=18) suggested that most adult IHO workers wear an employer-provided N95 respirator (15/17) and, less commonly, a surgical mask (2/17). Of the 17 whose employer provided them a mask, 16 did so in the past two weeks, and all 17 were using the mask provided. Employer training in face mask usage was also high (15/19) (**Table M3.1**), which may partly explain the high rate of use.[143]

Few, if any, biologically-relevant confounders were supported because numbers in baseline analyses were small (n=103). Problems with model convergence arose with the addition of confounders with even minimal missingness. This problem is partially ameliorated in the longitudinal analysis by using fixed-effects regression. Fixed-effects regression was also used to eliminate data collection on the vast array of unmeasurable confounders that arise from a lack of access to IHOs and from participant fear of reporting. The use of fixed-effects modeling controls for characteristics on IHOs that do not change over time, such as feed type[144] or barn construction (*e.g.*, floor slatting). To the best of our knowledge, this study is the first to apply fixed-effects regression as a tool to measure associations between self-reported workplace exposures and health outcomes in an IHO worker cohort.

Since quality of self-reporting was critical in this study, researchers included ten “dummy” symptoms (*i.e.,* without any known prior association with exposure to hog production facilities) on the questionnaires. Of those symptoms with fewer than eight cases reported, ten of the twenty were these dummy symptoms. None of these dummy symptoms were reported more than six times within the 752 person-records. This gives increased confidence in the quality of reporting in the face of possible personal incentives to overreport symptoms.

Other considerations for this study include, first of all, its cohort, which is a non-random, self-selected group and may lead to potential selection bias. That said, the recruited population reflects the occupational demographics of the area of Duplin, Sampson, and Bladen Counties in North Carolina. A second consideration is a lack of on-operation access; air sampling and personal monitoring could not be conducted on-site to corroborate survey responses. Further, these data are representative of IHO workers, who may represent a healthy-worker population. Fourth, baseline analyses lack needed temporality to make conclusions regarding causality even though the addition of eight follow-up visits improved upon the results. The small sample size (n=103) of our baseline analyses make the results highly sensitive to outliers. Due to the number of comparisons, we did not make any Bonferroni corrections. With the number of exposure and outcome associations examined it is possible to have spurious results. However, when examining the number, magnitude, and direction of these estimates, we see strong consistency. Finally, while some of the questions in the Basinas *et al*. study are absent,[123] others have been added giving a wider range of exposures and outcomes.

CONCLUSIONS

This evaluation of a wide variety of exposures and self-reported health outcomes among industrialized hog operation workers every two weeks for four months provides a broader understanding of the physical impacts on IHO workers than previous studies have been able to present. The data captured suggest that intense exposures to pigs and pig dust are detrimental to health and should be avoided or minimized by using personal protective equipment (masks and eye protection) and handwashing. Further research should focus on what types of facemasks are most appropriate and functional in this workplace environment. Type of mask, proper use, and employer provision of masks and training are all factors for consideration.

TABLES

Table 1.1. Baseline demographic and household characteristics of the industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

	Reports
Workers in cohort, n	103
Age in years, mean (SD)	38 (11)
	Reports, n (%)
Sex	
Male	55 (54)
Female	46 (46)
Race/ethnicity	
Hispanic, non-black	88 (88)
Black	12 (12)
Education status	
Less than high school education	47 (47)
High school degree/GED or higher	52 (53)
Body mass index (BMI)	
<30.0	58 (56)
≥30.0	38 (37)
Used a gym or workout facility in the last three months	
Yes	9 (9)
No	92 (91)
Current cigarette smoker	
Yes	13 (17)
No	65 (83)
Health insurance	
Yes	48 (48)
No	52 (52)
Place where IHO workers seek medical care[a]	
Private doctor	49 (49)
Emergency department or urgent care center	29 (28)
Hospital	18 (17)
Free clinic	16 (16)
Other	3 (3)
Does not seek medical care under any circumstance	4 (4)
Had a cat or dog	
Yes	44 (43)
No	50 (47)
Lived on same property as an IHO	
Yes	8 (8)
No	89 (92)
Month of baseline visit	
January	1 (1)
February	50 (49)
October	30 (29)
November	22 (21)

[a]Categories are not mutually exclusive.

Table 1.2. Baseline self-reported occupational exposure activities among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

Characteristic	Total responses (n)	Affirmative responses (n)	Mean (SD)
Years worked on any IHO	87	-	8 (6)
Days worked per week	97	-	6.4 (0.8)
Percent of time at work spent in direct contact with pigs	94	-	82 (27)
Characteristic	**Total responses (n)**	**Affirmative responses (n)**	**%**
Ever handled dead pigs	98	77	79
Ever gave pigs shots or injections	98	68	69
Ever came into direct contact with or touched pig manure	91	61	67
Ever gave antibiotics to pigs	97	60	62
Ever drew blood or collect other fluids from pigs	98	9	9
Only worked with	94		
Sows, nursery, and/or weaning pigs		46	48
Feeder and/or finisher pigs		24	25
Ever applied pesticides inside or around the barns	98	48	49
Wore coveralls/full body suit	97		
Always		68	70
Sometimes		14	14
Never		15	16
Wore a mask	98		
Always		37	38
Sometimes		43	44
Never		18	18
Wore glasses/goggles	98		
Always		22	22
Sometimes		34	35
Never		42	43
Work clothes ever washed with the laundry of household members	96	16	17

Table 1.3. Baseline self-reported health conditions[a] among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

	Prevalence, n (%)
Ever had eye irritation	19 (19)
Within the last month	12 (63)
Ever had nose irritation	16 (16)
Within the last month	10 (67)
Ever had throat irritation	15 (15)
Within the last month	13 (87)
Any allergies	13 (13)
Doctor-diagnosed asthma	9 (9)

[a]Participants were asked to not report health outcomes that they attributed to having a cold.

Table 1.4. Crude baseline associations between binary (unless noted as tertiles) self-reported industrial hog operation (IHO) work activities and binary self-reported symptoms among industrial hog operation (IHO) workers, North Carolina, 2013-2014, clustered at the household level.

	Have you ever had								
	Eye, nose, or throat symptoms			Any allergies			Doctor-diagnosed asthma		
	n	PR (95% CI)	p for trend	n	PR (95% CI)	p for trend	n	PR (95% CI)	p for trend
Have you ever									
Given pigs shots and/or antibiotics	96	2.23 (0.75, 6.63)		97	0.56 (0.20, 1.54)		97	1.04 (0.21, 5.22)	
Drawn pigs blood	97	**3.67 (1.93, 6.95)**		98	**4.40 (1.67, 12)**		98	3.30 (0.93, 12)	
Handled pig manure	90	0.95 (0.37, 2.41)		91	1.31 (0.38, 4.57)		91	1.48 (0.31, 6.99)	
Applied pesticides in or around the barns	97	**2.19 (1.00, 4.80)**		98	2.34 (0.80, 6.85)		98	1.04 (0.23, 4.66)	
Washed work clothes with household laundry	95	**2.30 (1.00, 5.29)**		96	0.45 (0.06, 3.32)		96	0.71 (0.09, 5.67)	
Do you typically									
Work exclusively in sow, nursery, and/or farrow barns	93	0.77 (0.34, 1.71)		94	0.52 (0.17, 1.58)		94	2.09 (0.41, 11)	
Work exclusively in feeder and/or finisher barns	93	1.29 (0.54, 3.07)		94	1.03 (0.31, 3.44)		-	-	
Always wear coveralls/full body suit, mask, and eye protection	96	1.27 (0.47, 3.36)		97	**3.76 (1.43, 9.88)**		97	2.63 (0.56, 12)	
Work 7 days per week	96	0.39 (0.14, 1.09)		97	**0.09 (0.01, 0.62)**		97	0.34 (0.07, 1.66)	
Years worked on any IHO									
Tertile 1 (1-5 years)	85	Ref (1.0)	**0.006**	85	Ref (1.0)	0.628	87	Ref (1.0)	0.290
Tertile 2 (6-10 years)		1.86 (0.45, 7.63)			0.58 (0.13,2.58)			3.55 (0.35, 35)	
Tertile 3 (11-27 years)		**4.29 (1.50, 12)**			0.76 (0.21, 2.70)			3.00 (0.30, 30)	
Percent of life working on any IHO									
Tertile 1 (2.4-11.6%)	82	Ref (1.0)	**0.042**	83	Ref (1.0)	0.810	55	Ref (1.0)	0.101
Tertile 2 (11.7-26.3%)		1.79 (0.44, 7.21)			1.04 (0.29, 3.75)			1.45 (0.25, 8.38)	
Tertile 3 (26.4-51.9%)		3.35 (0.99, 11)			0.84 (0.20, 3.47)			-	

PR = prevalence ratio. CI = confidence interval. - = model did not converge.

Table 1.5. Time-varying occupational exposure activities occurring during the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

	Exposures activities in the past week	Total responses (n)	Affirmative responses (n)	Mean (SD)
	Number of days worked	781	-	6 (1)
	Number of hours worked	748	-	42 (12)
	Number of hours in direct contact	742	-	38 (14)
	Number of sick pigs	742	-	61 (166)
	Number of dead pigs	744	-	42 (120)
	% of time coveralls/full body suit were worn	735	-	81 (38)
	% of time a mask was used	736	-	54 (46)
	% of time eye protection used	729	-	28 (42)
	Number of times washed hands at the IHO	738	-	8 (6)

	Exposures activities in the past week	Total responses (n)	Affirmative responses (n)	%
Barn condition score factors	Vent fans were off	736	178	24
	Malodor			
	None, moderate	739	564	76
	Extreme		175	24
	Temperature in the barns			
	Cold, comfortable	725	614	85
	Hot		111	15
	A new herd entered the barn(s)	743	47	6
	Dustiness in barns			
	None, moderate	737	705	96
	Extreme		32	4
Cleaning and pesticide score factors	Used cleaning chemical(s) at the IHO	745	414	56
	Pressure washed	747	290	39
	Applied pesticides	747	224	30
	Used a torch	749	20	3
Pig contact score factors	Gave pigs medicine	743	241	68
	Gave pigs shots	740	363	49
	Received an influenza vaccine since the last study visit	746	21	3

SD = standard deviation.

Table 1.6. Time-varying acute health outcomes occurring during the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

Symptoms in the past week	**Total responses (n)**	**Affirmative responses (n)**	**%**
At least one respiratory symptom	760	43	6
Excessive coughing	763	22	3
Runny nose	762	20	3
Difficulty breathing	761	12	2
Sore throat	760	5	1
At least one symptom interfered with sleep	745	26	3
Any symptoms reported	757	10	1
Waking from sleep due to coughing	753	15	2
Waking from sleep due to wheezing	752	11	1
Waking from sleep due to phlegm	752	9	1
Sneezing	762	19	2
Headache	762	15	2
Any mucus membrane	763	15	2
Eye irritation	762	11	1
Nose irritation	754	8	1

Table 1.7a. Crude time-varying acute health outcomes and scored work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	At least one respiratory symptom*			At least one symptom interfered with sleep**		
	obs. (groups)	OR (95% CI)	p for trend	obs. (groups)	OR (95% CI)	p for trend
Barn conditions score[a]						
0	224 (31)	Ref (1.0)	**0.001**	152 (21)	Ref (1.0)	0.344
1		2.51 (0.76, 8.28)			1.47 (0.40, 5.41)	
2 or more		**7.31 (2.13, 25)**			1.88 (0.51, 6.89)	
Cleaning score[b]						
0	226 (31)	Ref (1.0)	**0.015**	147 (20)	Ref (1.0)	**0.010**
1		2.00 (0.64, 6.18)			2.10 (0.36, 12)	
2 or more		**3.49 (1.26, 9.61)**			**7.34 (1.56, 34)**	
Pig contact score[c]						
0	223 (30)	Ref (1.0)	**<0.001**		-	
1		4.03 (0.98, 17)				
2		**10 (2.64, 42)**				
Score components[d]						
0 or 1	215 (30)	Ref (1.0)	**<0.001**	144 (20)	Ref (1.0)	**0.013**
2 or 3		**15 (1.76, 130)**			1.88 (.40, 8.80)	
4 to 6		**32 (3.63, 296)**			**7.77 (1.35, 45)**	
PPE score [e,f]						
0	226 (31)	Ref (1.0)	0.487	154 (21)	Ref (1.0)	0.299
1		0.34 (0.08, 1.51)			**0.09 (0.01, 0.92)**	
2		0.33 (0.05, 2.07)			0.08 (0.01, 1.10)	
3		0.32 (0.04, 2.53)			0.11 (0.01, 2.28)	
Number of times washed hands per shift						
Tertile 1 (0-6)	228 (31)	Ref (1.0)	0.157	147 (20)	Ref (1.0)	0.379
Tertile 2 (7-10)		0.46 (0.18, 1.15)			0.55 (0.16, 1.89)	
Tertile 3 (11-50)		0.49 (0.12, 2.05)			2.13 (0.53, 8.58)	

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE = personal protective equipment

* = Excessive coughing, runny nose, difficulty breathing, or sore throat
** = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval. - = model did not converge.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table 1.7b. Crude time-varying acute health outcomes and scored work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Sneezing			Headache			Eye or nose irritation		
	obs. (groups)	OR (95% CI)	p for trend	obs. (groups)	OR (95% CI)	p for trend	obs. (groups)	OR (95% CI)	p for trend
Barn conditions score[a]									
0	85 (12)	Ref (1.0)	0.857	92 (12)	Ref (1.0)	0.088	82 (11)	Ref (1.0)	**0.018**
1		0.83 (0.18, 3.85)			1.92 (0.43, 8.53)			5.98 (0.62, 58)	
2 or more		0.86 (0.19, 3.85)			3.35 (0.83, 13)			**12 (1.29, 119)**	
Cleaning score[b]									
0	85 (12)	Ref (1.0)	**0.007**		-			-	
1		0.86 (0.14, 5.27)							
2 or more		**11 (2.05, 63)**							
Pig contact score[c]									
0	87 (12)	Ref (1.0)	**0.019**	93 (12)	Ref (1.0)	0.082	70 (9)	Ref (1.0)	**0.007**
1		3.78 (0.20, 73)			3.90 (0.52, 29)			7.84 (0.61, 101)	
2		**18 (1.59, 208)**			5.18 (0.81, 33)			**20 (2.09, 196)**	
Score components[d]									
0 or 1	85 (12)	Ref (1.0)	0.058	92 (12)	Ref (1.0)	**0.022**	67 (9)	Ref (1.0)	**0.010**
2 or 3		3.23 (0.80, 13)			2.38 (0.54, 11)			7.18 (.64, 80)	
4 to 6		4.73 (0.91, 25)			**6.12 (1.29, 29)**			**22 (1.81, 273)**	
PPE score[e,f]									
0	85 (12)	Ref (1.0)	0.855	90 (12)	Ref (1.0)	0.428	82 (11)	Ref (1.0)	0.418
1		**0.09 (0.01, 0.96)**			0.93 (0.14, 6.29)			**0.04 (0.00, 0.54)**	
2		0.28 (0.13, 6.10)			0.61 (0.02, 21)			0.68 (0.07, 6.40)	
3		0.96 (0.02, 40)			0.20 (0.00, 11)			1.57 (0.06, 40)	
Number of times washed hands per shift									
Tertile 1 (0-6)	87 (12)	Ref (1.0)	0.574	93 (12)	Ref (1.0)	0.638	85 (11)	Ref (1.0)	0.928
Tertile 2 (7-10)		0.46 (0.09, 2.28)			0.85 (0.16, 4.46)			0.93 (0.20, 4.39)	
Tertile 3 (11-50)		2.18 (0.37, 13)			1.70 (0.23, 12)			0.93 (0.15, 5.63)	

[a]*Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)*
[b]*Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)*
[c]*Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)*
[d]*Number of individual activities/conditions (maximum 10)*
[e]*Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)*
[f]*PPE = personal protective equipment*

OR = odds ratio. CI = confidence interval. - = model did not converge.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table 1.8a. Crude time-varying acute health outcomes and binary work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	At least one respiratory symptom*		At least one symptom interfered with sleep**	
	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	225 (31)	**3.99 (1.37, 12)**	152 (21)	1.66 (0.52, 5.28)
Conducted any pesticide application or cleaning activity[b]	229 (31)	**2.95 (1.15, 7.52)**	147 (20)	**4.49 (1.09, 18)**
Administered pigs medicine or shots[c]	223 (30)	**6.76 (1.84, 25)**		-
Two or three of the above categories[d]	215 (30)	**10 (2.22, 46)**	144 (20)	**19 (2.09, 171)**
Used any PPE [e,f]	226 (31)	0.34 (0.08, 1.50)	154 (21)	**0.08 (0.01, 0.84)**
Washed hands at least 8 times per shift[g]	228 (31)	**0.32 (0.12, 0.83)**	147 (20)	0.62 (0.21, 1.84)

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

* = Excessive coughing, runny nose, difficulty breathing, or sore throat.
** = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

OR = odds ratio. CI = confidence interval. - = model did not converge.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table 1.8b. Crude time-varying acute health outcomes and binary work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Sneezing		Headache		Eye or nose irritation	
	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	85 (12)	0.84 (0.22, 3.27)	92 (12)	2.60 (0.75, 8.99)	84 (11)	**8.43 (1.00, 71)**
Conducted any pesticide application or cleaning activity[b]	86 (12)	3.46 (0.97, 12)	93 (12)	1.91 (0.51, 7.10)	85 (11)	2.61 (0.64, 11)
Administered pigs medicine or shots[c]	87 (12)	**12 (1.33, 105)**	93 (12)	4.61 (0.84, 25)	70 (9)	**15 (1.67, 133)**
Two or three of the above categories[d]	85 (12)	**4.06 (1.06, 16)**	92 (12)	**7.48 (1.40, 40)**	67 (9)	**6.10 (1.32, 28)**
Used any PPE [e,f]	85 (12)	0.10 (0.01, 1.02)	90 (12)	0.92 (0.14, 6.21)	82 (11)	**0.14 (0.02, 0.88)**
Washed hands at least 8 times per shift[g]	87 (12)	0.88 (0.24, 3.16)	93 (12)	1.27 (0.30, 5.40)	85 (11)	0.57 (0.15, 2.24)

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE = personal protective equipment
[g]8 is the median number of times workers reported washing their hands per IHO work shift

OR = odds ratio. CI = confidence interval.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

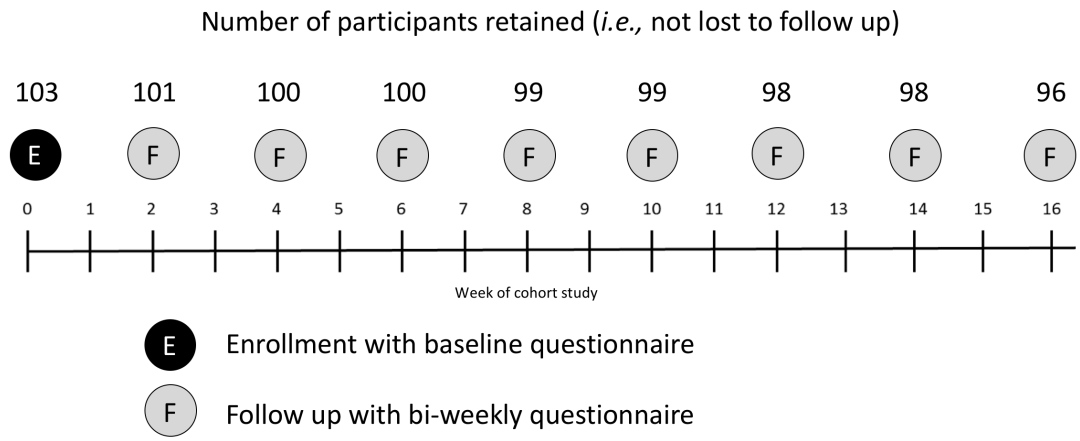

Figure 1.1. Sampling scheme and loss-to-follow-up between the baseline and bi-weekly study visits within a cohort of industrial hog operation (IHO) workers, North Carolina, 2013-2014.

SUPPLEMENTAL MATERIAL

Table S1.1. Age- and sex-adjusted baseline associations between binary (unless noted as tertiles) self-reported industrial hog operation (IHO) work activities and binary self-reported symptoms among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

	Eye, nose, or throat symptoms			Have you ever had Any allergies			Doctor-diagnosed asthma		
	n	PR (95% CI)	p for trend	n	PR (95% CI)	p for trend	n	PR (95% CI)	p for trend
Have you ever									
Given pigs shots and/or antibiotics	-	-		91	0.49 (0.18, 1.38)		95	0.86 (0.19, 4.01)	
Drawn pigs blood	-	-		95	**3.97 (1.50, 10)**		95	2.70 (0.78,9.29)	
Handled pig manure	88	1.03 (0.39, 2.76)		89	1.46 (0.44, 4.86)		89	1.91 (0.39, 9.35)	
Applied pesticides in or around the barns	-	-		95	2.11 (0.71, 6.28)		95	1.09 (0.20, 6.06)	
Washed work clothes with household laundry	-	-		93	0.55 (0.07, 4.44)		93	0.83 (0.11, 6.42)	
Do you typically									
Work exclusively in sow, nursery, and/or farrow barns	-	-		91	0.42 (0.11, 1.61)		91	1.41 (0.16, 12)	
Work exclusively in feeder and/or finisher barns	90	1.85 (0.81, 4.21)		91	1.14 (0.30, 4.28)		-	-	
Always wear coveralls/full body suit, mask, and eye protection	93	1.16 (0.39, 3.45)		94	**3.86 (1.64, 9.09)**		94	2.19 (0.48, 10)	
Work 7 days per week	-	-		94	**0.09 (0.01, 0.66)**		94	0.38 (0.07, 1.95)	
Years worked on any IHO									
Tertile 1 (1-5 years)	77	Ref (1.0)	**0.011**	83	Ref (1.0)	0.708	84	Ref (1.0)	0.066
Tertile 2 (6-10 years)		1.96 (0.39, 9.82)			0.84 (0.17, 4.19)			7.27 (0.78, 68)	
Tertile 3 (11-27 years)		**4.56 (1.43, 15)**			1.39 (0.36, 5.29)			6.02 (0.60, 60)	
Percent of life working on any IHO									
Tertile 1 (2.4-11.6%)	-	-	-	83	Ref (1.0)	0.855	55	Ref (1.0)	0.144
Tertile 2 (11.7-26.3%)		-			1.29 (0.33, 5.12)			1.76 (0.11, 28)	
Tertile 3 (26.4-51.9%)		-			1.11 (0.27, 4.61)			-	

PR = prevalence ratio. CI = confidence interval. - = model did not converge.

Table S1.2a. Binary exposures and outcomes from the past week, with results from two-by-two tables reported as having at least 5 data points in each cell (x) or having fewer than five in at least one cell (-).

In the past week	Used chemicals	Gave pigs shots	Pressure washed	Gave pigs medicine	Extreme dust	Used pesticides	Vent fans off
At least one respiratory symptom	x	x	x	x	x	x	x
Excessive coughing	x	x	x	x	-	x	x
Runny nose	x	x	x	x	x	x	x
Difficulty breathing	x	x	x	x	-	x	x
Sore throat	-	-	-	-	-	-	-
At least one symptom interfered with sleep	x	x	x	x	-	x	x
Any sleep symptoms reported	-	-	-	-	-	-	-
Waking from sleep due to coughing	x	x	x	x	-	-	-
Waking from sleep due to wheezing	x	x	-	-	-	-	-
Waking from sleep due to phlegm	-	-	-	-	-	-	-
Sneezing	x	x	x	x	x	x	x
Headache	-	x	-	x	x	x	x
Any mucus membrane symptoms	x	x	x	x	x	x	x
Eye irritation	x	-	-	-	x	x	x
Nose irritation	-	-	-	-	-	-	-

Table S1.2b. Binary exposures and outcomes from the past week, with results from two-by-two tables reported as having at least 5 data points in each cell (x) or having fewer than five in at least one cell (-).

In the past week	Extreme malodor	Contact with breeding pigs	Hot inside barns	New herd	Pigs brought from an off-site location	Used a torch	Received a flu shot
At least one respiratory symptom	x	x	x	-	-	-	-
Excessive coughing	x	x	-	-	-	-	-
Runny nose	x	x	-	-	-	-	-
Difficulty breathing	x	-	-	-	-	-	-
Sore throat	-	-	-	-	-	-	-
At least one symptom interfered with sleep	x	x	-	-	-	-	-
Any sleep symptoms reported	-	-	-	-	-	-	-
Waking from sleep due to coughing	x	-	-	-	-	-	-
Waking from sleep due to wheezing	x	-	-	-	-	-	-
Waking from sleep due to phlegm	-	-	-	-	-	-	-
Sneezing	x	-	x	-	-	-	-
Headache	x	-	x	-	-	-	-
Any mucus membrane symptoms	x	-	-	-	-	-	-
Eye irritation	x	-	-	-	-	-	-
Nose irritation	-	-	-	-	-	-	-

Table S1.3a. Crude models of time varying binary exposures and outcomes using fixed-effects regression. Results are presented as OR (95% CI).

In the past week	Used chemicals	Gave pigs shots	Pressure washed	Gave pigs medicine	Extreme dust
At least one respiratory symptom	1.16 (0.47, 2.89)	**2.89 (0.99, 8.44)**	2.23 (0.82, 6.09)	1.45 (0.61, 3.42)	2.50 (0.40, 16)
Excessive coughing	1.50 (0.34, 6.50)	**5.45 (0.99, 30)**	4.07 (0.55, 30)	1.58 (0.46, 5.37)	-
Runny nose	9.15 (0.55, 151)	10 (0.43, 237)	1.29 (0.22, 7.51)	1.76 (0.31, 9.98)	10 (0.25, 418)
Difficulty breathing	2.10 (0.45, 9.91)	0.63 (0.08, 4.76)	2.30 (0.45, 12)	2.20 (0.38, 13)	-
At least one symptom interfered with sleep	1.39 (0.41, 4.76)	4.02 (0.62, 26)	2.62 (0.68, 10)	2.15 (0.62, 7.41)	0.28 (0.02, 3.92)
Any sleep symptoms reported	0.52 (0.05, 5.59)	#	3.27 (0.20, 52)	#	#
Waking from sleep due to coughing	0.99 (0.22, 4.49)	6.58 (0.60, 72)	1.17 (0.26, 5.27)	2.70 (0.46, 16)	0.80 (0.06, 11)
Waking from sleep due to wheezing	0.77 (0.10, 5.74)	#	-	-	-
Waking from sleep due to phlegm	0.58 (0.08, 4.42)	3.22 (0.20, 51)	0.60 (0.07, 5.20)	1.59 (0.13, 19)	#
Sneezing	2.23 (0.37, 13)	#	1.08 (0.17, 6.79)	#	1.62 (0.16, 16)
Headache	-	0.45 (0.03, 6.39)	-	0.38 (0.03, 4.36)	0.39 (0.03, 4.49)
Any mucus membrane symptoms	2.18 (0.15, 32)	2.90 (0.23, 37)	1.42 (0.18, 11)	1.46 (0.16, 14)	0.46 (0.02, 12)
Eye irritation	#	-	-	-	#

OR = odds ratio. CI = confidence interval. # = model did not converge

- = Due to *a priori* considerations of small numbers of events we did not estimate OR (95% CI) for the following outcomes: sore throat, any sleep symptoms reported, waking from sleep due to phlegm, nose irritation, new herd, pigs brought from an off-site location, use of a torch, and flu shot since the last visit).

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.3b. Crude models of time varying binary exposures and outcomes using fixed-effects regression. Results are presented as OR (95% CI).

In the past week	Used pesticides	Vent fans off	Extreme malodor	Contact with breeding pigs	Hot inside barns
At least one respiratory symptom	**2.80 (1.02, 7.70)**	1.34 (0.40, 4.48)	**2.53 (1.05, 6.12)**	3.41 (0.52, 22)	3.44 (0.75, 16)
Excessive coughing	1.85 (0.45, 7.63)	0.39 (0.03, 4.48)	3.02 (0.62, 15)	7.73 (0.52, 116)	-
Runny nose	-	0.18 (0.01, 3.60)	2.65 (0.52, 14)	3.87 (0.12, 120)	-
Difficulty breathing	**7.30 (1.14, 47)**	3.63 (0.49, 27)	5.45 (0.85, 35)	-	-
At least one symptom interfered with sleep	**6.79 (1.41, 33)**	1.90 (0.46, 7.80)	1.54 (0.49, 4.82)		-
Any sleep symptoms reported	#	0.96 (0.12, 7.60)	0.12 (0.01, 1.57)	#	3.09 (0.16, 59)
Waking from sleep due to coughing	1.91 (0.34, 11)	2.01 (0.33, 12)	**8.55 (1.40, 52)**	1.07 (0.15, 7.59)	#
Waking from sleep due to wheezing	-	-	0.55 (0.04, 8.36)		
Waking from sleep due to phlegm	#	#	3.59 (0.20, 65)	0.32 (0.02, 6.63)	#
Sneezing	#	0.15 (0.01, 1.60)	1.06 (0.23, 4.92)	-	1.05 (0.09, 12)
Headache	5.58 (0.49, 64)	3.39 (0.22, 53)	1.66 (0.30, 9.15)	-	#
Any mucus membrane symptoms	1.76 (0.13, 25)	#	4.26 (0.45, 40)	-	-
Eye irritation	1.74 (0.10, 30)	#	4.21 (0.27, 65)	-	-

OR = odds ratio. CI = confidence interval. # = model did not converge

- = Due to *a priori* considerations of small numbers of events we did not estimate OR (95% CI) for the following outcomes: sore throat, any sleep symptoms reported, waking from sleep due to phlegm, nose irritation, new herd, pigs brought from an off-site location, use of a torch, and flu shot since the last visit)

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.4. Crude models of time varying continuous industrial hog operation (IHO) work exposure activities and binary respiratory and other health outcomes among industrial hog operation (IHO) workers, North Carolina, 2013-2014. Results are presented as OR (95% CI).

In the past week	Number of days worked	Number of hours worked (per 10)	Direct contact hours (per 10)	Number of sick pigs (per 100)	Number of dead pigs (per 100)	Number of times washed hands
At least one respiratory symptom	1.33 (0.79, 2.26)	1.52 (0.89, 2.58)	1.17 (0.78, 1.75)	1.06 (0.82, 1.36)	1.17 (0.85, 1.61)	0.88 (0.77, 1.01)
Excessive coughing	1.46 (0.73, 2.93)	1.73 (0.84, 3.57)	1.24 (0.70, 2.21)	**2.53 (1.10, 5.82)**	1.46 (0.88, 2.41)	**0.70 (0.54, 0.91)**
Runny nose	1.83 (0.77, 4.38)	4.44 (0.64, 31)	0.95 (0.49, 1.82)	2.38 (0.57, 9.90)	1.14 (0.74, 1.76)	0.85 (0.69, 1.05)
Difficulty breathing	1.06 (0.63, 1.80)	1.30 (0.59, 2.86)	1.81 (0.80, 4.10)	0.94 (0.58, 1.52)	1.28 (0.36, 4.47)	1.00 (0.95, 1.06)
Sore throat	1.00 (0.25, 4.00)	#	#	#	#	#
At least one symptom interfered with sleep	1.28 (0.74, 2.21)	1.45 (0.83, 2.54)	1.09 (0.72, 1.64)	1.20 (0.97, 1.48)	1.77 (0.82, 3.86)	0.98 (0.90, 1.07)
Any sleep symptoms reported	1.15 (0.38, 3.44)	59 (0.18, 19318)	0.87 (0.38, 1.98)	1.11 (0.86, 1.45)	11 (0.11, 1020)	1.09 (0.89, 1.34)
Waking from sleep due to coughing	1.79 (0.83, 3.88)	1.74 (0.87, 3.47)	1.08 (0.70, 1.66)	1.22 (0.88, 1.69)	0.89 (0.45, 1.76)	0.94 (0.81, 1.09)
Waking from sleep due to wheezing	1.50 (0.35, 6.48)	5.47 (0.61, 49)	3.99 (0.60, 27)	2.26 (0.23, 22)	#	1.47 (0.70, 3.10)
Waking from sleep due to phlegm	5.99 (0.64, 57)	6.22 (0.39, 99)	1.45 (0.70, 3.03)	28 (0.15, 5415)	18 (0.08, 3904)	0.89 (0.61, 1.32)
Sneezing	1.18 (0.59, 2.36)	1.14 (0.59, 2.17)	1.01 (0.63, 1.63)	1.56 (0.35, 6.84)	1.28 (0.65, 2.53)	1.02 (0.86, 1.21)
Headache	1.15 (0.61, 2.16)	1.20 (0.53, 2.72)	1.75 (0.85, 3.61)	5.51 (0.38, 79)	1.63 (0.30, 8.83)	1.02 (0.89, 1.17)
Any mucus membrane symptoms	0.44 (0.10, 2.04)	1.11 (0.44, 2.79)	4.18 (0.71, 25)	2.52 (0.11, 56)	1.44 (0.48, 4.36)	0.93 (0.77, 1.14)
Eye irritation	1.03 (0.19, 5.74)	0.75 (0.23, 2.47)	1.40 (0.56, 3.52)	#	1.34 (0.57, 3.15)	0.98 (0.73, 1.32)
Nose irritation	0.54 (0.11, 2.62)	3.80 (0.55, 26)	49 (0.80, 2957)	2.73 (0.45, 17)	1.66 (0.64, 4.29)	0.92 (0.72, 1.17)

OR = odds ratio. CI = confidence interval. # = model did not converge

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.5a. Calendar month (dummy variable)-adjusted time-varying acute health outcomes and work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	At least one respiratory symptom*			At least one symptom interfered with sleep**		
	obs. (groups)	OR (95% CI)	p for trend	obs. (groups)	OR (95% CI)	p for trend
Barn conditions score[a]						
0	224 (31)	Ref (1.0)	**0.010**	152 (21)	Ref (1.0)	0.822
1		4.40 (0.70, 28)			1.11 (0.20, 6.13)	
2 or more		**11 (1.58, 84)**			1.24 (0.18, 8.36)	
Cleaning score[b]						
0	226 (31)	Ref (1.0)	0.061	147 (20)	Ref (1.0)	0.071
1		1.47 (0.44, 4.89)			1.35 (0.19, 9.77)	
2 or more		3.00 (0.94, 9.54)			4.67 (0.80, 27)	
Pig contact score[c]						
0	223 (30)	Ref (1.0)	**0.043**		-	
1		2.44 (0.53, 11)				
2		**4.42 (1.00, 19)**				
Score components[d]						
0 or 1		-		144 (20)	Ref (1.0)	0.087
2 or 3					1.78 (0.19, 16)	
4 to 6					8.95 (0.52, 153)	
PPE score [e,f]						
0	226 (31)	Ref (1.0)	0.705	154 (21)	Ref (1.0)	-
1		0.95 (0.18, 4.92)			1.83 (0.08, 44)	
2		0.71 (1.0, 4.86)			1.22 (0.04, 36)	
3		1.92 (0.20, 18)			3.91 (0.10, 148)	
Number of times washed hands per shift						
Tertile 1 (0-6)	228 (31)	Ref (1.0)	0.058	147 (20)	Ref (1.0)	0.980
Tertile 2 (7-10)		0.44 (0.15, 1.30)			0.39 (0.08, 1.91)	
Tertile 3 (11-50)		0.21 (0.04, 1.23)			0.63 (0.09, 4.50)	

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE = personal protective equipment

* = Excessive coughing, runny nose, difficulty breathing, or sore throat
** = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval. - = model did not converge.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.5b. Calendar month (dummy variable)-adjusted time-varying acute health outcomes and work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Sneezing obs. (groups)	Sneezing OR (95% CI)	Sneezing p for trend	Headache obs. (groups)	Headache OR (95% CI)	Headache p for trend	Eye or nose irritation obs. (groups)	Eye or nose irritation OR (95% CI)	Eye or nose irritation p for trend
Barn conditions score[a]									
0	85 (12)	Ref (1.0)	0.982	92 (12)	Ref (1.0)	0.164	82 (11)	Ref (1.0)	0.096
1		0.50 (0.04, 6.72)			2.51 (0.34, 19)			3.15 (0.21, 48)	
2 or more		0.79 (0.08, 8.30)			5.26 (0.51, 54)			14 (0.64, 302)	
Cleaning score[b]									
0	85 (12)	Ref (1.0)	0.114		-			-	
1		0.42 (0.04, 4.84)							
2 or more		4.72 (0.71, 32)							
Pig contact score[c]									
0		-		93 (12)	Ref (1.0)	0.421	70 (9)	Ref (1.0)	0.51
1					1.03 (0.04, 27)			3.12 (0.16, 60)	
2					0.31 (0.01, 6.93)			2.68 (0.16, 46)	
Score components[d]									
0 or 1	85 (12)	Ref (1.0)	0.314	92 (12)	Ref (1.0)	0.571	67 (9)	Ref (1.0)	0.33
2 or 3		3.55 (0.54, 23)			3.12 (0.23, 42)			4.05 (0.30, 55)	
4 to 6		3.09 (0.28, 34)			2.57 (0.16, 41)			5.47 (0.24, 126)	
PPE score[e,f]									
0		-			-			-	
1									
2									
3									
Number of times washed hands per shift									
Tertile 1 (0-6)	87 (12)	Ref (1.0)	0.746	93 (12)	Ref (1.0)	0.624		-	
Tertile 2 (7-10)		0.09 (0.01, 1.38)			0.51 (0.04, 5.89)				
Tertile 3 (11-50)		0.81 (0.03, 19)			1.64 (0.14, 19)				

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE (personal protective equipment)

* = Excessive coughing, runny nose, difficulty breathing, or sore throat
** = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval. - = model did not converge.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.6a. Calendar month (dummy variable)-adjusted time-varying acute health outcomes and binary work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	At least respiratory symptom*		At least one symptom interfered with sleep**	
	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	225 (31)	**5.93 (1.06, 33)**	152 (21)	1.15 (0.23, 5.84)
Conducted any pesticide application or cleaning activity[b]	229 (31)	2.45 (0.89, 6.71)	147 (20)	2.88 (0.54, 15)
Administered pigs medicine or shots[c]	223 (30)	3.38 (0.83, 13)		-
Two or three of the above categories[d]	215 (30)	5.11 (0.95, 27)	144 (20)	8.30 (0.92, 75)
Used any PPE [e,f]	226 (31)	0.93 (0.18, 4.70)	154 (21)	1.78 (0.08, 39)
Washed hands at least 8 times per shift[g]	228 (31)	**0.24 (0.08, 0.75)**	147 (20)	0.56 (0.12, 2.50)

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE = personal protective equipment
[g]8 is the median number of times workers reported washing their hands per IHO work shift

* = Excessive coughing, runny nose, difficulty breathing, or sore throat
** = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.6b. Calendar month (dummy variable)-adjusted time-varying acute health outcomes and binary work activities the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Sneezing		Headache		Eye or nose irritation	
	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)	obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	85 (12)	0.67 (0.08, 5.96)	92 (12)	3.25 (0.50, 21)	84 (11)	6.25 (0.52, 74)
Conducted any pesticide application or cleaning activity[b]	86 (12)	1.94 (0.38, 10)	93 (12)	1.35 (0.25, 7.47)	85 (11)	1.17 (0.13, 10)
Administered pigs medicine or shots[c]		-	93 (12)	0.51 (0.03, 7.73)	70 (9)	2.87 (0.22, 38)
Two or three of the above categories[d]	85 (12)	2.25 (0.36, 14)	92 (12)	3.40 (0.30, 39)	67 (9)	2.56 (0.36, 18)
Used any PPE [e,f]		-		-		-
Washed hands at least 8 times per shift[g]	87 (12)	0.24 (0.03, 1.78)	93 (12)	1.25 (0.15, 10)		-

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0)
[f]PPE = personal protective equipment
[g]8 is the median number of times workers reported washing their hands per IHO work shift

OR = odds ratio. CI = confidence interval.

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.7a. Time-varying odds ratios of at least one respiratory symptom and binary work activities in the week immediately preceding the biweekly study visit, stratified by overall protective actions throughout the study among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Overall mask usage	n obs. (groups)	OR (95% CI)	Overall coveralls/full body suit usage	n obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	≥ 80%			≥ 80%	172 (24)	**3.48 (1.02, 11.94)**
	< 80%			< 80%	53 (7)	5.88 (0.64, 54)
Conducted any pesticide application or cleaning activity[b]	≥ 80%	112 (15)	3.30 (0.78, 13.96)	≥ 80%	176 (24)	**4.03 (1.36, 11.96)**
	< 80%	117 (16)	2.70 (0.79, 9.24)	< 80%	53 (7)	1.01 (0.17, 5.91)
Administered pigs medicine or shots[c]	≥ 80%	113 (15)	5.77 (0.51, 65)	≥ 80%	170 (23)	**7.24 (1.52, 34.40)**
	< 80%	110 (15)	**7.19 (1.52, 33.92)**	< 80%	53 (7)	5.70 (0.52, 62)
Performed or experienced two or three of the above	≥ 80%			≥ 80%		
	< 80%			< 80%		

[a]Reported at least one of the following: extreme temperature, extreme malodor, extreme dust, vents off, or a new herd entering the barns
[b]Reported at least one of the following: used cleaning chemicals and/or pesticides, pressure washed or used a torch
[c]Reported at least one of the following: gave pigs shots and/or medicine

OR = odds ratio. CI = confidence interval.
Grey = at least one cell did not did not converge
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

Table S1.7b. Time-varying odds ratios of at least one respiratory symptom and binary work activities in the week immediately preceding the biweekly study visit, stratified by overall protective actions throughout the study among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

In the past week	Average number of handwashes per shift	n obs. (groups)	OR (95% CI)
Any hot or dusty barn conditions[a]	≥ 8	75 (10)	3.29 (0.49, 22.21)
	< 8	150 (21)	**4.35 (1.17, 16.15)**
Conducted any pesticide application or cleaning activity[b]	≥ 8	75 (10)	5.38 (0.90, 32)
	< 8	154 (21)	2.33 (0.80, 6.73)
Administered pigs medicine or shots[c]	≥ 8		
	< 8		
Performed or experienced two or three of the above	≥ 8	75 (10)	**9.83 (1.07, 90)**
	< 8	140 (20)	**10.98 (1.29, 83)**

[a]Reported at least one of the following: extreme temperature, extreme malodor, extreme dust, vents off, or a new herd entering the barns
[b]Reported at least one of the following: used cleaning chemicals and/or pesticides, pressure washed or used a torch
[c]Reported at least one of the following: gave pigs shots and/or medicine

OR = odds ratio. CI = confidence interval.
Grey = at least one cell did not did not converge
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

OR (95% CI) estimates are derived from conditional logistic fixed-effects regression models, which estimate the average of all within-person differences between time-varying exposure and outcome.

CHAPTER 2

The relation of common industrial hog operation work activities with spirometry measurements in a prospective worker cohort, North Carolina, USA

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ABSTRACT

Background: Declines in swine worker lung function are well documented in the literature; however, the work activities related to these declines are not well defined. Understanding which activities are more or less detrimental to respiratory health could improve the lives of the more than 33,000 industrial hog operation (IHO) workers in the U.S. through the ability to make recommendations on when workers should don personal protective equipment (PPE).

Objectives: To identify IHO work activities associated with diminished respiratory function, at baseline and longitudinally, and the protective effect, if any, of PPE.

Methods: Using spirometers, 103 IHO workers were measured at baseline and 101 were followed for up to 8 bi-weekly (*i.e.,* every two weeks) visits. At each visit, lung function measurements were collected and work activities self-reported on a questionnaire. Generalized linear and linear fixed-effects models were fitted to identify activities and protective measures significantly associated with respiratory outcomes.

Results: An inexpensive, portable, and user-friendly spirometer (Piko-1) was used to capture acute changes in lung function over time in an IHO worker cohort. The adequacy of the device was shown in the congruence between its measurements and that of a reference instrument (Koko). At baseline, reports of typically working seven days per week, years worked on any IHO, and ever giving pigs shots and/or antibiotics were associated with diminished lung function. Ever using pesticides was associated with improved lung function, an indication of healthy worker effect bias. Fixed-effects regression analyses were also employed, and this underutilized statistical method assisted in the reduction of confounding within longitudinal models. Over time it was noted that coveralls were worn more often when workers

performed more and dirtier activities, while they removed face protection with increased and dirtier work activities. Face and body protection when worn consistently together were often more protective than either alone.

Conclusions: Lung function declines the more IHO workers are on-operation. Workers take off face protection, but don body protection as barn conditions and tasks worsen. Face and body protection should be worn on-IHO, especially during activities that are dusty and necessitate close contact with pigs. On-the-job training and intervention trials should be conducted to bolster the use of PPE and ensure those who are using PPE are using the equipment properly.

INTRODUCTION

Swine agricultural workers[145] and veterinarians[146] are at higher risk for adverse respiratory health outcomes than the general public.[147-149] However, most studies have examined cross-sectional,[57,150-152] long-term (*i.e.,* chronic),[125,153] or cross-shift (*i.e.,* sub-acute)[26,27,118,150,154] changes in lung function, not those on an acute temporal scale. Further, not all pig production operations are equally detrimental. Exposures differ depending on the type, density, and scale of production. Air sampling studies of facilities have reported that personal exposures include endotoxin,[57,125,152] ammonia (NH_3),[57,152,155] hydrogen sulfide (H_2S), dust,[57] dander, feed, and microbes,[156,157] with alarming proportions of collected bacteria resistant to two or more antibiotics.[158]

Industrial hog operation (IHO) studies that employ spirometry to measure lung function of workers are dated, and most recent investigations rely solely on self-reported health outcomes. Among U.S. studies that employ objective measures of lung function (*i.e.,* spirometry) is a 1995 study by Schwartz *et al*. that found pig workers were exposed to higher concentrations of dust and had greater work shift declines in FEV_1 and FVC than a control group of non-swine farmers.[58] A study from the same group looked at cross-shift changes in spirometry measurements with exposure to dust as measured by personal and workplace monitoring.[27]

Newer studies focus strongly on chronic obstructive pulmonary disease (COPD) and have not updated our understanding of other health outcomes, even as pig farming practices evolve and workers have had additional time employed on IHOs since their inception in the 1970s. Further, prospective cohort studies are lacking in this population. A systematic review by Douglas *et al*. found that only 2 of 16 published studies in this working population were from prospective cohorts.[147] This is not surprising, as previous studies have called for additional work to identify workplace factors that account for the high prevalence of respiratory symptoms in IHO worker populations.[159]

Documenting the deleterious effects of IHOs on the respiratory health of workers in the U.S. has been a challenge historically. Workers' unwillingness to participate in scientific studies for fear of termination, limited access to operations, and corporate influence[13] have meant that the studies undertaken were short-term, lacked the ability to determine changes to health on a granular level, and/or were conducted outside the U.S. Lack of updated data hinders priority setting for the occupational health of the ~33,000 IHO workers in the U.S.[35]

Past studies have primarily focused on the difference in lung function between IHO workers and the general public or pig farmers or IHO workers and other agricultural workers.[13,58,140,150,151] The work presented here is unique in that by employing fixed-effects regression analyses,[137] workers are compared to themselves, thus removing confounding from fixed characteristics (*e.g.,* participant age, sex, race/ethnicity, structural differences in barns, and at-home characteristics), which may be present in others' models. To the best of the authors' knowledge, this is the first time fixed-effects regression has been used to assess spirometry with IHO work activities. The purpose of this current investigation is to examine the effect a variety of IHO work activities have on lung function changes (*i.e.,* spirometric measurements) on the acute scale.

METHODS

Study design

At each of nine study visits, a questionnaire (either baseline or bi-weekly) adapted from the Agricultural Health Study and the American Thoracic Society[135] was administered by community investigators to collect information regarding work practices. Spirometry was also completed at each visit via a Piko-1 spirometer. At baseline, a reference instrument (Koko machine) was also used (**Figure 2.1**).

Setting

Participants from the top 10 hog-producing counties in North Carolina were enrolled. Enrollment has been previously detailed.[116] In short, it was conducted on a rolling basis from October 2013 through February 2014. Participants were followed for a maximum of 16 weeks, with a visit from study staff every two weeks. Participants completed a questionnaire and performed spirometry outside of work hours, either at home or in a public place.

Participants

Participants were eligible for inclusion in the sample population if they were current IHO workers (full- or part-time) and agreed to participate in the study. IHO workers were eligible for inclusion in the baseline analysis population if they were enrolled in the study and were eligible for inclusion in the longitudinal analysis population if they completed at least two follow-up visits. Recruitment was performed by Rural Empowerment for Community Help (REACH) personnel using word of mouth and personal connections.

Questionnaire

Estimates of work practices and conditions

As detailed in earlier work,[116] all questionnaires were administered by research staff. The enrollment survey instrument was designed to gather data regarding typical work activities and underlying health characteristics. Specific questions were worded as what participants "typically," "usually," or "ever" did on-operation and what environmental conditions they were "typically," "usually," or "ever" exposed to at work.

At each follow-up study visit information about the frequency, magnitude, and duration of participants' contact with pigs, job activities, personal behaviors (*e.g.,* cigarette use), and personal protective equipment (PPE) use was collected. Each question was asked about the week prior. For example, "In the past week have you…"

Assessment of lung function

Lung function was assessed by spirometry. A portable Piko-1 pulmonary function device, which records forced expiratory volume in the first second (FEV_1) and peak expiatory flow rate (PEFr), was used over all study visits by a community worker. This handheld, portable asthma-tracking tool can be operated without requiring an individual who had completed formal training in NIOSH-spirometry to be on-site. Additionally, a Koko-brand machine was employed by a NIOSH-trained coach at baseline. The Koko machine had a wider range of measurements including:

FEV_1, PEFr, forced vital capacity (FVC), the ratio of forced expiratory volume in the first second to forced vital capacity (FEV_1/FVC), forced expiratory volume in six seconds (FEV_6), forced expiratory flow at 25-75% of the pulmonary volume (FEF25-75%), and the ratio of forced expiratory volume in the first second to forced expiratory volume in six seconds (FEV_1/FEV_6). Ultimately, in analyses only the Piko-1 measurements and FEV_1, PEFr, FVC, FEV_1/FVC Koko measurements were used. Three good trials, as defined by the American Thoracic Society (ATS)[160] and the National Institute for Occupational Safety and Health (NIOSH) standards,[161] were attempted for each testing session unless the participant was physically unable to complete the three spirometric maneuvers. The best maneuver per study visit for each person was used in data analysis.

Data analysis

Exposure variables with limited variability (fewer than 10 cases reported over the 752 study visits) were *a priori* dropped from analyses to reduce any bias associated with small numbers.

At baseline, years worked on any IHO and percentage of life working on an IHO were transformed from continuous variables to tertiles due to non-linearity. Average days worked per week and percentage of time at work spent in direct contact with pigs were transformed into binary variables due to non-linearity and skewed distributions. Due to collinearity, reports of workers who ever gave pigs shots and/or antibiotics were combined into a single category.

Spirometry measurements were modeled as continuous variables, with percent predicted (using reported age, race/ethnicity, and height as predictors in the Hankinson 1999 reference values[162]) at baseline and raw measurements over time.

Drawing on past work in longitudinal analyses [unpublished Coffman, 2018], the following unweighted exposure categories and scores were created: (1) *barn conditions* consisting of reports of binary extreme temperature, extreme malodor, extreme dust, vent fans turned off or non-existent at the facility, and a new herd entering the barn(s); (2) *cleaning activities* composed of cleaning chemical use, pesticide use, pressure washing, and torch use; (3) *pig contact*, meaning gave pigs shots and/or gave pigs medicine; and (4) an unweighted sum of all the aforementioned activities with 1 assigned to those reported being done or experienced and 0 to those not reported, for a possible total of 0 to 10. Consistency of PPE use was defined as a worker reporting the gear was worn at least 80% of the time. All exposures were from reports of experiences in the past week.

Confounders of interest from the literature and relevant to baseline generalized linear models clustered at the household level include: cigarette smoking, hour of test, and interviewer. Fixed-effects linear regression was used to control for measured and unmeasured confounding in longitudinal analyses. Confounders of interest from the literature and relevant to inclusion in fixed-effects models include: cigarette smoking, hour of test, month of test, and interviewer. A dummy variable was used for hour of test, as this diurnal pattern is not linear.[163]

Spirometry data were analyzed in two ways: (1) all data from the best try (*i.e.,* no cough, inhale, or delay in start, and a good effort) was used; and (2) as a sensitivity analysis for each model, only measurements fulfilling ATS/NIOSH standards,[160,161] with three good tries and two repeatable measurements making an acceptable overall test, were used (see **Supplement**). The decision to use all spirometry measurements (regardless of ATS/NIOSH acceptability) as main analyses and restricting measurements to those that met ATS/NIOSH validity criteria as sensitivity analyses was based on: (1) Piko-1 devices were not designed to conform to American Thoracic Society (ATS) criteria; (2) only the first three maneuvers were recorded using the Piko-1 device (more maneuvers would have met reproducibility had the Koko been used throughout the study); (3) point estimates between the main and sensitivity analyses were similar; and (4) ATS/NIOSH criteria state that to have a "valid" test both FEV_1 and FVC measures must have three good tries and both must have two measurements within 0.15L of each other. Since the Piko-1 device does not assess FVC, this would have made even acceptable FEV_1 measurements technically invalid.

Crude analyses are reported as main analyses, while fully adjusted models are shown as sensitivity analyses because: (1) point estimates between the two remain consistent; (2) fixed-effects models do not suffer from the same necessity for adjustment as other random effects models; and (3) baseline models are unable to converge with many adjustments for confounders. Correction to the α level for significance was not made for multiple comparisons.

Data was analyzed using Stata (StataCorp. 2017. *Stata* Statistical Software: Release 15. College Station, TX: *StataCorp* LP).

RESULTS

At baseline, 103 workers entered the cohort, 101 were retained past enrollment, and 100 were retained until at least the third visit (**Figure 2.1**). Of the 101 persons eligible for data analysis, 98% of study visits were completed and 92 of the 101 completed all eight follow-up visits. In examining key characteristics between those who were able to complete spirometry tests and those who were not, the only profound difference at baseline was that more non-smokers than smokers were able to provide Koko maneuvers. Overall, more participants were able to provide Piko-1 measurements (99 of 103) than Koko measurements (69 of 103) (**Table 2.1**).

The concordance between Piko-1 and Koko measurements when using all the best maneuvers was relatively low (R^2: 0.79 for FEV_1 measures and R^2: 0.40 for PEFr measures) (**Table 2.4**). However, when restricting the analysis set to those with ATS/NIOSH-acceptable spirometry (three tries recorded and the best two within 0.15L for FEV_1 or 0.67L for PEFr), the R^2 values increase, as shown in **Table S2.1**. The workers who did not meet ATS/NIOSH standards for acceptable spirometry measurements had worse lung function, as measured by FEV_1, than those who met the ATS/NIOSH standards. Those who did not meet the ATS/NIOSH criteria had greater PEFr measurements than those who did. Using Bland-Altman plots, Koko FEV_1 values were greater than Piko-1 for the same individuals; however, Piko-1 values for PEFr were greater than paired Koko values (data not shown).

In this occupational cohort, very few participants had obstructive or restrictive lung disease (**Table 2.5**), as classified either by the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria[164] or by using the lower limit of normal (LLN) as a cutoff for healthy versus non-healthy lung function.

Using the most reported symptoms at baseline [unpublished Coffman, 2018], crude analyses (clustered to account for household) of percent predicted values were run using all six available spirometric outcomes to assess for the need to include these symptoms as confounders in subsequent models (**Table 2.6a and 2.6b**). In crude models, only reports of any doctor-diagnosed asthma was significant associated with lung function declines.

Ten binary self-reported measures of exposure and two variables transformed into tertiles were examined in association with the six baseline measures of lung function. In this crude analysis, six associations were statistically significant, with two of these relationships (FEV_1/FVC and pesticide application; PEFr and extensive personal protective equipment [PPE] use) in the hypothesized direction. Worse lung function was seen in those who worked on any IHO longer than those in the first tertile, with significant associations for trends in 3 of 12 models (**Tables 2.7a - 2.7c**). Those who reported working seven days per week *vs.* any fewer days also had declines in lung function as measured by PEFr (L/s) (**Table 2.7c**).

When using the same exposure-outcome models in **Tables 2.7a - 2.7c** and adjusting for the dummy variables of hour of spirometric test (either by the time recorded by the Koko machine, when available, or end-of-survey time if not), current cigarette smoking (binary), month of test (dummy), and interviewer (dummy), the relationship between pesticide application and FEV_1/FVC held (**Table S2.2b**). The associations between giving pigs shots or antibiotics and PEFr (**Table S2.2b**). and working seven days per week and PEFr were also maintained (**Table S2.2c**). The associations between tertiles of length of time working on any IHO weakened, although 9 of 12 remained in the negative direction. Sensitivity analyses (not shown) were performed using other confounders, including reports of physical symptoms. On the basis of AIC and prior knowledge the more parsimonious model with the three above confounders was selected.

Due to the nature of the differences in baseline compared with follow-up surveys, spirometry for visits 1-8 for those with two or more visits was also examined (**Table 2.8**). Reports of exposure activities in the past week and spirometry measurements from the most recent visit showed limited changes in respiratory function within categories (p for trend analyses) (**Tables 2.10 and S2.11**). However, PPE use was statistically significant in the un-hypothesized adverse direction in both crude and adjusted models by score and in binary models (**Tables 2.11 and S2.12**).

To further explore the relationship between PPE use and diminished lung function this un-hypothesized association was then examined using fixed-effects linear regression (**Table 2.12**). While consistent face protection usage (defined as at least 80% mask and/or eye protection in the past week) showed negligible effects on respiratory function, the consistent use of body protection (defined as at least 80% coverall/full body suit utilization in the past week) was associated with declines in FEV_1 (ß: -0.23; 95% CI: -0.43, -0.03) and PEFr (ß: -0.53; 95% CI: -1.07, 0.01).

Examining which workers are more likely to wear certain PPE, Pearson chi-squared tests for associations between on-IHO work activities and PPE use (**Table 2.13**) and reported symptoms and PPE use was then employed (**Table 2.14**). While symptoms were not meaningfully associated with different levels of PPE utilization, work activities were. “U”-shaped trends were observed between many of the individual work activities and PPE, while linear trends with score components and PPE were observed. Importantly, body protection use increased as more on-IHO work activities were reported, while face protection declined.

To examine the effect multiple PPE types may have on lung function, we then looked at interactions between face and body protection (**Table 2.15**), which showed significant declines in lung function.

We then stratified **Table 2.13** by each work activity category (**Tables 2.15-2.20b**) to test the hypothesis that using both forms of PPE when performing a task was more beneficial than using one or no forms of PPE. In each analysis, compared to the referent group of those who used neither body or face protection, all PPE use was associated with declines in lung function. However, the use of both types was seen to be associated with lesser declines in lung function than those who used only one type.

DISCUSSION

In this study, a decline in mean lung function as time on IHOs increased was observed. This was seen in years worked on any IHO, percent of life worked on any IHO, and with those who worked seven days per week compared to those who worked less. At baseline, most significant lung declines were ~10% from the expected values, a clinically significant amount. Interestingly, the second tertile of percentage of life working on any IHO shows the greatest decrements in lung function. This may be due to the healthy worker effect, where those who continue working on any IHO and reach the highest tertile of time are the healthiest of workers and can withstand year-after-year exposures to dust and microbes. This phenomenon creates the appearance of improved lung function compared with workers in the second tertile of exposure. The health of the workers is also shown in **Table 2.4**, where spirometry values are within a reasonable, and often above average, range compared to the predicted values for our workers based on their age, race/ethnicity, and height.

Healthy worker effect bias was also seen in **Table 2.7b**, where reports of using pesticides were associated with improved lung function, a relationship not noted in other large pesticide exposure studies.[165]

It was also seen that those who self-report allergies have worse lung function than those who do not (**Table 2.6b**). Allergies may be due to seasonal (*e.g.,* pollen) or environmental effects (*e.g.,* house dust mites) but may also indicate individuals who are suffering from on-IHO effects and have misclassified them as being caused by a more "traditional" irritant. This hypothesis cannot be substantiated.

It was also seen that working seven days per week compared to less was associated with declines in lung function, as were years of life or percentage of life employed on any IHO (**Tables 2.7a – 2.7c**). The inverse relationship between time on IHO and lung function as measured by FEV_1 and FVC has been previously documented, but with hours per day worked as the explanatory variable.[149]

In longitudinal analyses it was observed that while workers were more likely to put on body protection as the number of tasks increased on-IHO, they were more likely to remove their face PPE (**Table 2.13a**). A protective measure that did improve acute lung function, although not significantly, was handwashing **(Tables 2.10 and 2.11**).

The majority of the workers were never smokers (**Table 2.1**). This is similar to an Irish farmer cohort[159] and in congruence with American Thoracic Society findings (1998). Unlike Cushen *et al.* who reported 13% of never smokers having airflow obstruction ($FEV_1/FVC < 0.70$),[159] a much smaller proportion (1%) is reported here using these same GOLD criteria (**Table 2.5**). When classifying obstruction by the lower limit of normal, the overall prevalence in this N.C. cohort is akin to Cushen *et al.*'s 11% and 8% of ever smokers (6 of 73). Cushen *et al.* also report the presence of airflow obstruction is significantly associated with self-reported allergy history and prior airway disease,[159] which is confirmed in this U.S. population (**Tables 2.6a and 2.6b**).

Iversen and Takai (1990) showed that working in pig houses was related to acute reduced lung function (FEV_1 and FVC) among farmers with physical respiratory symptoms as well as among farmers without any symptoms.[166] This trend was also observed here using fixed-effects regression (**Tables 2.10 and 2.11**) but no relationship was statistically significant at the α=0.05 level. In contrast, a 1992 study by Schwartz *et al.* found that IHO workers with respiratory healthy symptoms may have lung function impairment that is too early to detect with spirometric measurements,[167] and may explain the largely null findings in the longitudinal analyses.

In baseline analyses, an unexpected, negative relationship between age and lung function was observed. While in the general population lung function declines with age, Donham *et al.* saw that age improved pulmonary function in IHO workers,[27] and attributed it to healthy worker bias. However, due to reliance on Person correlation coefficients and not percent change or ß coefficients, quantitative comparison to the current study is limited. In another population, Donham *et al*. found that baseline FVC measurements were within 95% of predicted value,[150] an observation that was corroborated in this cohort (**Table 2.5**).

Healthy worker effect is a well-documented bias in many occupational settings, but not universal. One study found that those who remained in pig farming longer had higher FEV_1 measurements than those who left, and the odds of quitting pig operations was increased for workers on farms with greater than 400 head of swine and lower than predicted initial lung function.[168] Further limitations in generalizability include the possible differences between warmer climates (North Carolina) and colder climates, where ventilation systems may differ. No studies have compared the possible differences in temperature or humidity.[34]

Using subjects not previously exposed to a swine barn environment, Dosman *et al*. were able to demonstrate the effectiveness of a disposable N95 respirator for lung protection,[169] as were Palmberg *et al*.[170] It is possible that the same correlation was not observed in the current analysis due to the strong correlation between PPE and barn activities, where workers report removing their respiratory and eye protection as they perform more and dirtier tasks. From an occupational standpoint, the removal of face protective equipment makes sense: it can be cumbersome, it can hinder the ability to perform job tasks and communicate with other workers, and it becomes sweaty in hot environments. Since prior literature has shown face equipment has been shown to be protective, training and education interventions for workers performing increased numbers of dusty or dirty tasks should be a priority.

Workers also noted donning and continuing to wear their body protection with hot, dusty, and increased number of tasks. This can be explained by on-IHO practices, where anecdotally, in general, male workers (55% of the cohort) tend to wear very little clothing beneath their coveralls and therefore cannot remove them. Facemasks, in contrast, can be easily removed in hot, uncomfortable conditions. Further, at some IHOs coveralls are required by owners to protect pigs from humans, whereas facemasks and eye protection are not. While IHO workers were not queried directly on which masks were used, subsequent assessment of a small number of workers (n=18) in a follow-up study suggested that N95 facemasks were being used by workers, that they were provided by employers, and some training of their use was being given (**Table M3.1**).

This cohort of 103 IHO workers is a non-random, self-selected group, which may lead to potential selection bias. In contrast, however, the population is believed to represent the occupational population demographics within Duplin, Sampson, and Bladen Counties, the area from which they were enrolled. This research would not have been possible without the community-based participatory research and community-driven questions from REACH. They were key to enrolling participants and maintaining an ongoing relationship with IHO workers. The enrollment and retention of hard-to-reach non-white male and female workers performing the day-to-day operations on-IHO is rare. Following these workers on a bi-weekly time scale allowed the measurement of acute changes to lung function with recall of on-IHO work activities.

The use of the Piko-1 spirometer was also a strength. This easy-to-use handheld device allowed more measurements from workers than had a gold standard Koko tabletop device been used (**Tables 2.1 and 2.4**). The Piko-1 was also able to capture more smokers than the Koko. Of the smokers, 12 of 13 had Piko-1 measurements at baseline, while only 5 of 13 had Koko (**Table 2.1**). Considering that the Piko-1 is not a NIOSH gold standard instrument, it is worth noting that when ATS/NIOSH acceptability criteria are applied to these measurements, the resulting point estimates and confidence intervals were similar to those without these criteria applied. This gives confidence to use the expanded data set, as compared to analyzing only those that fit the ATS/NIOSH validity criteria. The use of the larger dataset also improved the power to detect associations in this population.

CONCLUSIONS

This study found that in healthy IHO workers in North Carolina, the longer a person worked on any IHO the worse their lung function, as measured by spirometry. It also showed that quality data can be collected through the use of a handheld, portable asthma-tracking device that does not require a NIOSH-trained technician to be on-site to operate. Further, PPE usage resulted in declines in the respiratory health of IHO workers but is believed to be strongly associated with increasing work activities, where more people wear body protection as they perform more tasks but remove their face (respiratory and eye) protection as on-IHO exposure activity increases. More research is needed to determine what kinds of masks are being used, how and what kind of coveralls are being worn, and what guidance is being provided to workers.

TABLES

Table 2.1. Differences in population characteristics stratified by available spirometry data from an industrial hog operation (IHO) worker cohort, 2013-2014.

Characteristic	Has Piko-1	Does not have Piko-1	Has Koko	Does not have Koko
Workers in cohort, n	99	4	69	34
Age in years, mean (SD)	38 (11)	25 (-)	39 (11)	35 (9)
Sex, n (%)				
Male	54 (55)	1 (50)	34 (49)	21 (66)
Female	45 (45)	1 (50)	35 (51)	11 (34)
Race/ethnicity, n (%)				
Hispanic, non-black	88 (90)	0 (0)	68 (100)	20 (63)
Black	10 (10)	2 (100)	0 (0)	12 (34)
Education status, n (%)				
Less than high school education	49 (51)	0 (0)	34 (51)	13 (41)
High school degree/GED or college	47 (49)	3 (100)	33 (49)	19 (59)
Height in centimeters, mean (SD)	165 (11)	-	165 (9)	166 (14)
Weight in pounds, mean (SD)	172 (32)	-	172 (31)	174 (35)
Body mass index (BMI), mean (SD)	29 (5)	-	29 (5)	29 (6)
Used a gym or workout facility in the last three months, (%)				
Yes	8 (8)	1 (50)	4 (6)	5 (16)
No	91 (92)	1 (50)	65 (94)	27 (84)
Current cigarette smoker, n (%)				
Yes	12 (16)	1 (100)	5 (7)	8 (73)
No	65 (84)	0 (0)	62 (93)	3 (37)
Had health insurance, n (%)				
Yes	46 (47)	2 (100)	34 (50)	14 (44)
No	52 (53)	0 (0)	34 (50)	18 (56)
Does not seek medical care under any circumstance, n (%)				
Yes	4 (4)	0 (0)	4 (6)	0 (0)
No	93 (96)	2 (100)	63 (94)	32 (100)
Hobbies outside of work (auto repair or use of chemicals), n (%)				
Yes	6 (6)	0 (0)	3 (4)	3 (10)
No	91 (94)	1 (100)	64 (96)	28 (90)
Had any pet that goes inside the home, n (%)				
Yes	18 (38)	-	15 (39)	3 (33)
No	29 (62)	-	23 (61)	6 (64)
Lived on same property as an IHO, n (%)				
Yes	8 (8)	0 (0)	7 (11)	1 (3)
No	87 (92)	2 (100)	58 (89)	31 (97)
Interviewer, n (%)				
A	2 (2)	0 (0)	0 (0)	2 (8)
B	41 (47)	2 (67)	37 (55)	6 (25)
C	35 (40)	1 (33)	28 (42)	8 (33)
D	10 (11)	0 (0)	2 (3)	8 (33)

SD = standard deviation.

Table 2.2. Baseline self-reported occupational exposure activities among industrial hog operation (IHO) workers, North Carolina, 2013-2014.[a]

Characteristic	Total responses (n)	Affirmative responses (n)	Mean (SD)
Years worked on any IHO	87	-	8 (6)
Days worked per week	97	-	6.4 (0.8)
Percent of time at work spent in direct contact with pigs	94	-	82 (27)

Characteristic	Total responses (n)	Affirmative responses (n)	%
Ever handled dead pigs	98	77	79
Ever gave pigs shots or injections	98	68	69
Ever came into direct contact with or touched pig manure	91	61	67
Ever gave antibiotics to pigs	97	60	62
Ever drew blood or collect other fluids from pigs	98	9	9
Only worked with			
Sows, nursery, and/or weaning pigs	94	46	48
Feeder and/or finisher pigs	94	24	25
Ever applied pesticides inside or around the barns	98	48	49
Wore coveralls/full body suit			
Always		68	70
Sometimes	97	14	14
Never		15	16
Wore a mask			
Always		37	38
Sometimes	98	43	44
Never		18	18
Wore glasses/goggles			
Always		22	22
Sometimes	98	34	35
Never		42	43
Work clothes ever washed with the laundry of household members	96	16	17

[a]Previously shown in Chapter 1

Table 2.3. Baseline self-reported health conditions among industrial hog operation (IHO) workers, North Carolina, 2013-2014.[a]

	Prevalence, n (%)
Eyes are ever sore or irritated	19 (19)
Within the last month	12 (63)
Nose is ever sore or irritated	16 (16)
Within the last month	10 (67)
Throat is ever sore or irritated	15 (15)
Within the last month	13 (87)
Any allergies	13 (13)
Doctor-diagnosed asthma	9 (9)

[a]Participants were asked to not report health outcomes that they attributed to having a cold.
Previously shown in Chapter 1.

Table 2.4. Descriptive statistics of all spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

Characteristic	n	Mean (SD)	n	Predicted Mean (SD)	n	Percent Predicted (SD)	R^2 for Piko-1 and Koko based on mean measurement
Koko							
FEV_1 (L)	69	3.2 (0.8)	67	3.4 (0.7)	67	95.4 (17.6)	-
PEFr (L/s)	68	6.6 (2.9)	66	4.8 (0.4)	66	138.2 (40.4)	-
FVC (L)	69	3.9 (0.9)	67	4.1 (0.8)	67	95.5 (17.6)	-
FEV_1/FVC	69	0.8 (0.1)	67	0.8 (0.0)	67	100.0 (7.2)	-
Piko-1							
FEV_1 (L)	98	3.0 (0.8)	92	3.4 (0.7)	92	89.6 (22.5)	0.79
PEFr (L/s)	99	7.1 (2.1)	93	4.9 (0.5)	93	146.6 (39.9)	0.40

SD = standard deviation

Table 2.5. Classification of adverse respiratory outcomes based on spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 (using all data).

Characteristic	**n**	**%**
Global Initiative for Chronic Obstructive Lung Disease (GOLD) [GOLD, 2016] (via Koko)		
Obstructive		
No	68	99
Yes	1	1
Restrictive		
No	68	99
Yes	1	1
Lower limit of normal (LLN)		
Obstructive (via Koko)		
No	67	100
Yes	0	0
Obstructive (via Piko-1)		
No	82	89
Yes	10	11
Restrictive (via Koko)		
No	67	100
Yes	0	0

Normal = FEV_1 and FVC above 80% predicted (LLN); FEV_1/FVC ratio above 0.70 (GOLD)
Obstructive = FEV_1 below 80% predicted (LLN); FEV_1/FVC ratio below 0.70 (GOLD)
Restrictive = FVC below 80% predicted (LLN); FEV_1/FVC ratio above 0.70 (GOLD)

Table 2.6a. Crude relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1[a]		**% Predicted FVC[a]**		**% Predicted PEFr[a]**		**% Predicted FEV_1/FVC[a]**	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	64	4.49 (-6.13, 15.12)	64	3.58 (-6.47, 13.62)	63	0.25 (-17.46, 17.96)	64	-0.42 (-3.28, 2.44)
Any allergies	66	-11.90 (-26.20, 2.41)	66	-12.09 (-25.90, 1.71)	65	-11.20 (-50.12, 27.72)	66	0.31 (-4.35, 4.96)
Doctor-diagnosed asthma	67	-10.92 (-23.31, 1.45)	67	-9.40 (-22.99, 4.18)	66	-1.60 (-27.27, 24.07)	67	-1.59 (-5.74, 2.57)

[a]Performed on a Koko spirometer

Table 2.6b. Crude relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1[a]		% Predicted PEFr[a]	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	89	5.41 (-6.24, 17.07)	96	4.34 (-9.65, 18.32)
Any allergies	91	-1.54 (-23.58, 20.51)	97	8.59 (-14.19, 31.38)
Doctor-diagnosed asthma	92	**-10.89 (-20.73, -1.05)**	99	1.42 (-13.01, 15.85)

[a]Performed on a Piko-1 spirometer

Table 2.7a. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level.

	% Predicted FEV1[a]			% Predicted FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	65	-0.34 (-9.54, 8.86)		65	-2.99 (-11.45, 5.48)	
Drawn pigs blood	65	5.00 (-19.77, 29.77)		65	1.07 (-18.43, 20.57)	
Handled pig manure	65	0.72 (-7.50, 8.95)		65	0.11 (-8.71, 8.92)	
Applied pesticides in or around the barns	65	0.01 (-8.02, 8.05)		65	-4.31 (-12.67, 4.05)	
Washed work clothes with household laundry	64	0.75 (-10.70, 12.20)		64	-1.00 (12.28, 10.27)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	63	1.96 (-6.82, 10.75)		63	0.54 (-8.32, 9.39)	
Work exclusively in feeder and/or finisher barns	63	-3.88 (-12.72, 4.96)		63	-2.39 (-11.29, 6.52)	
Always wear a mask and bodysuit and eye protection	64	4.91 (-4.07, 13.89)		64	4.52 (-6.49, 15.52)	
Work 7 days per week	65	0.73 (-7.40, 8.86)		65	2.05 (-6.22, 10.32)	
100% of time at work spent in direct contact with hogs	64	-6.66 (-15.48, 2.17)		64	-6.97 (-15.69, 1.75)	
Years worked on any IHO						
Tertile 1 (1-5 years)	62	Ref (0.0)	**0.043**	62	Ref (0.0)	**0.030**
Tertile 2 (6-10 years)		**-10.25 (-19.87, -0.63)**			**-10.12 (-20.24, -0.002)**	
Tertile 3 (11-27 years)		**-9.77 (-19.31, -0.22)**			**-10.79 (-20.57, -1.02)**	
Percent of life working on any IHO						
Tertile 1 (2.4-11.6%)	62	Ref (0.0)	0.315	62	Ref (0.0)	0.372
Tertile 2 (11.7-26.3%)		**-12.35 (-22.80, -1.89)**			-9.13 (-20.74, 2.48)	
Tertile 3 (26.4-51.9%)		-6.45 (-18.19, 5.29)			-5.82 (-17.63, 5.99)	

[a]Performed on a Koko spirometer

Table 2.7b. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	64	-21.03 (-43.78, 1.72)		65	3.44 (-0.16, 7.06)	
Drawn pigs blood	64	3.51 (-22.87, 29.88)		65	2.09 (-2.79, 6.96)	
Handled pig manure	64	3.69 (-17.08, 24.45)		65	0.40 (-2.94, 3.74)	
Applied pesticides in or around the barns	64	4.77 (-15.87, 25.40)		65	**4.28 (0.86, 7.71)**	
Washed work clothes with household laundry	63	9.66 (-16.88, 36.20)		64	1.37 (-2.52, 5.26)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	62	7.67 (-14.66, 30.00)		63	1.96 (-1.10, 5.02)	
Work exclusively in feeder and/or finisher barns	62	-11.62 (-35.67, 12.43)		63	-1.83 (-5.91, 2.26)	
Always wear a mask and bodysuit and eye protection	63	-3.46 (-37.15, 30.22)		64	0.29 (-3.70, 4.28)	
Work 7 days per week	64	-14.39 (-36.26, 7.47)		65	-1.71 (-4.73, 1.32)	
100% of time at work spent in direct contact with hogs	63	5.66 (-14.41, 25.73)		64	0.54 (-3.15, 4.23)	
Years worked on any IHO						
Tertile 1 (1-5 years)	61	Ref (0.0)	0.360	62	Ref (0.0)	0.741
Tertile 2 (6-10 years)		-13.26 (-41.40, 14.89)			-0.72 (-5.83, 4.39)	
Tertile 3 (11-27 years)		-11.49 (-36.86, 13.88)			0.57 (-2.58, 3.71)	
Percent of life working on any IHO						
Tertile 1 (2.4-11.6%)	61	Ref (0.0)	0.907	62	Ref (0.0)	0.618
Tertile 2 (11.7-26.3%)		-15.10 (-43.51, 13.31)			**-4.32 (-8.49, -0.14)**	
Tertile 3 (26.4-51.9%)		1.19 (-28.76, 31.14)			-1.22 (-5.17, 2.73)	

[a]Performed on a Koko spirometer

Table 2.7c. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level.

	% Predicted FEV_1[a]			% Predicted PEFr[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	90	5.72 (-4.27, 15.72)		95	7.41 (-10.27, 25.08)	
Drawn pigs blood	90	6.34 (-16.34, 29.01)		96	3.41 (-19.22, 26.04)	
Handled pig manure	85	-1.85 (-11.54, 7.84)		90	-8.00 (-26.00, 10.00)	
Applied pesticides in or around the barns	90	-0.98 (-10.25, 8.29)		96	-1.18 (-18.02, 15.66)	
Washed work clothes with household laundry	88	3.14 (-12.96, 19.24)		94	9.16 (-10.54, 28.85)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	87	4.44 (-7.13, 16.00)		92	4.67 (-11.22, 20.57)	
Work exclusively in feeder and/or finisher barns	80	-4.55 (-10.25, 1.16)		92	-8.02 (-24.34, 8.31)	
Always wear a mask and bodysuit and eye protection	89	9.13 (-5.10, 23.36)		95	**23.95 (5.55, 42.34)**	
Work 7 days per week	89	0.58 (-8.39, 9.55)		95	**-19.85 (-35.01, -4.68)**	
100% of time at work spent in direct contact with hogs	87	-9.43 (-19.46, 0.60)		92	-10.60 (-27.14, 5.94)	
Years worked on any IHO						
Tertile 1 (1-5 years)	80	Ref (0.0)	0.118	86	Ref (0.0)	0.681
Tertile 2 (6-10 years)		-6.41 (-18.01, 5.18)			-1.92 (-19.42, 15.59)	
Tertile 3 (11-27 years)		-8.92 (-20.10, 2.25)			-4.00 (-22.87, 14.87)	
Percent of life working on any IHO						
Tertile 1 (2.4-11.6%)	80	Ref (0.0)	**0.050**	83	Ref (0.0)	0.908
Tertile 2 (11.7-26.3%)		**-14.85 (-27.50, -2.20)**			-17.20 (-37.49, 3.09)	
Tertile 3 (26.4-51.9%)		**-12.20 (-24.32, -0.09)**			-0.77 (-20.36, 18.81)	

[a]Performed on a Piko-1 spirometer

Table 2.8. Descriptors of spirometry measurements over time (of those workers with at least two follow-up visits) within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

			Predicted values[a]				
Characteristic	**n**	**Mean (SD)**	**n**	**Mean (SD)**	**n**	**% (SD)**	**t-test that mean is different between full data and valid data Pr(|T| > |t|)**
All best FEV_1 (L) measured by Piko-1	737	2.85 (0.82)	92	3.44 (0.71)	737	84.55 (24.89)	-
All best PEFr (L/sec) measured by Piko-1	737	6.53 (2.29)	92	4.89 (0.49)	736	134.02 (45.71)	-
Best FEV_1 (L) if three tries and <0.15L	430	2.86 (0.70)	51	3.29 (0.77)	430	84.79 (20.26)	0.90
Best PEFr (L/sec) if three tries and <0.67L	374	6.60 (2.30)	48	4.90 (0.53)	426	134.8 (44.4)	0.63

SD = standard deviation.

[a]Using Hankinson 1999 reference values.[162]

Table 2.9. Time-varying occupational exposure activities occurring during the week immediately preceding the biweekly study visit among industrial hog operation (IHO) workers, North Carolina, 2013-2014.

	Exposures activities in the past week	**Total responses (n)**	**Affirmative responses (n)**	**Mean (SD)**
	Number of days worked	781	-	6 (1)
	Number of hours worked	748	-	42 (12)
	Number of hours in direct contact	742	-	38 (14)
	Number of sick pigs	742	-	61 (166)
	Number of dead pigs	744	-	42 (120)
	% of time coveralls/full body suit were worn	735	-	81 (38)
	% of time a mask was used	736	-	54 (46)
	% of time eye protection used	729	-	28 (42)
	Number of times washed hands at the IHO	738	-	8 (6)
	Exposures activities in the past week	**Total responses (n)**	**Affirmative responses (n)**	**%**
Barn condition score factors	Vents were off	736	178	24
	Malodor			
	None, moderate	739	564	76
	Extreme		175	24
	Temperature in the barns			
	Cold, comfortable	725	614	85
	Hot		111	15
	A new herd entered the barn(s)	743	47	6
	Dustiness in barns			
	None, moderate	737	705	96
	Extreme		32	4
Cleaning and pesticide score factors	Used cleaning chemical(s) at the IHO	745	414	56
	Pressure washed	747	290	39
	Applied pesticides	747	224	30
	Used a torch	749	20	3
Pig contact score factors	Gave pigs medicine	743	241	68
	Gave pigs shots	740	363	49
	Received an influenza vaccine since the last study visit	746	21	3

SD = standard deviation.
Previously shown in Chapter 1.

Table 2.10. Crude relationship between reported exposure scores and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression.

In the past week	FEV$_1$ (L) visits (workers)*	FEV$_1$ (L) ß (95% CI)	FEV$_1$ (L) p for trend	PEFr (L/s) visits (workers)*	PEFr (L/s) ß (95% CI)	PEFr (L/s) p for trend
Barn conditions score[a]						
0	693 (99)	Ref (0.0)	0.287	693 (99)	Ref (0.0)	0.198
1		-0.02 (-0.17, 0.13)			-0.11 (-0.51, 0.28)	
2		-0.19 (-0.38, 0.002)			-0.37 (-0.88, 0.14)	
3 or 4		0.07 (-0.25, 0.39)			-0.22 (-1.07, 0.62)	
Cleaning score[b]						
0	717 (99)	Ref (0.0)	0.102	717 (99)	Ref (0.0)	0.185
1		0.01 (-0.15, 0.18)			-0.13 (-0.56, 0.31)	
2		0.05 (-0.12, 0.23)			0.10 (-0.36, 0.56)	
3 or 4		0.17 (-0.03, 0.38)			0.33 (-0.20, 0.86)	
Pig contact score[c]						
0	715 (100)	Ref (0.0)	0.232	715 (100)	Ref (0.0)	0.304
1		-0.05 (-0.22, 0.11)			-0.14 (-0.57, 0.29)	
2		-0.10 (-0.28, 0.07)			-0.24 (-0.69, 0.21)	
Score components[d]						
0 or 1	680 (99)	Ref (0.0)	0.772	687 (99)	Ref (0.0)	0.734
2 or 3		-0.06 (-0.22, 0.11)			0.12 (-0.32, 0.56)	
4, 5, or 6		0.01 (-0.18, 0.19)			0.11 (-0.38, 0.59)	
PPE score[e,f]						
0	712 (100)	Ref (0.0)	0.290	712 (100)	Ref (0.0)	0.878
1		**-0.33 (-0.58, -0.08)**			-1.07 (-1.74, -0.39)	
2		**-0.42 (-0.74, -0.11)**			-0.97 (-1.81, -0.14)	
3		-0.31 (-0.65, 0.04)			-0.63 (-1.55, 0.29)	

Number of times washed hands per shift						
Tertile 1 (0-6)	717 (100)	Ref (0.0)	0.836	717 (100)	Ref (0.0)	0.152
Tertile 2 (7-10)		0.04 (-0.11, 0.18)			0.27 (-0.11, 0.64)	
Tertile 3 (11-50)		0.003 (-0.22, 0.23)			0.36 (-0.22, 0.94)	

[a]Sum of extreme temperature (yes=1, no=0), extreme malodor (yes=1, no=0), extreme dust (yes=1, no=0), vents off (yes=1, no=0), and a new herd entering the barn(s) (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), used pesticides (yes=1, no=0), pressure washed (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs shots (yes=1, no=0) and gave pigs medicine (yes=1, no=0)
[d]Sum of all above components, with a possible total of 0 to 11.
[e]Sum of consistently (≥80% of the time at work) wore the following: mask (yes=1, no=0), glasses (yes=1, no=0), and bodysuit/coveralls (yes=1, no=0)
[f]PPE = personal protection equipment

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a Piko-1 spirometry test result.

Table 2.11. Crude relationship between reported exposure scores (binary) and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression.

In the past week	FEV$_1$ (L)		PEFr (L/s)	
	visits (workers)*	ß (95% CI)	visits (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	700 (99)	-0.06 (-0.20, 0.08)	700 (99)	-0.18 (-0.55, 0.19)
Performed a cleaning activity[b]	720 (99)	0.05 (-0.10, 0.19)	720 (99)	0.03 (-0.35, 0.41)
Had pig contact[c]	718 (100)	-0.07 (-0.22, 0.08)	718 (100)	-0.15 (0.54, 0.23)
Performed two or three of the above[d]	687 (99)	0.02 (-0.13, 0.16)	687 (99)	0.01 (-0.37, 0.40)
Used any protection consistently[e]	712 (100)	**-0.33 (-0.59, -0.08)**	712 (100)	**-1.06 (-1.74, -0.39)**
Handwashing at least 8 times per shift[f]	717 (100)	0.08 (-0.06, 0.22)	717 (100)	0.29 (-0.07, 0.65)
Worked seven days	738 (101)	-0.07 (-0.20, 0.07)	738 (101)	0.05 (-0.31, 0.41)
Worked at least 45 hours	728 (101)	0.004 (-0.12, 0.13)	728 (101)	0.33 (-0.01, 0.67)

[a]Reported at least one of the following: extreme temperature, extreme malodor, extreme dust, vents off, or a new herd entering the barns
[b]Reported at least one of the following: used cleaning chemicals and/or pesticides, pressure washed or used a torch
[c]Reported at least one of the following: gave hogs shots and/or medicine
[d]Binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f] 8 is the median

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a Piko-1 spirometry test result.

Table 2.12. Crude longitudinal relationship between reported personal protective equipment (PPE) and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	visits (workers)*	ß (95% CI)	visits (workers)*	ß (95% CI)
Used body protection consistently[a]	719 (101)	**-0.23 (-0.43, -0.03)**	719 (101)	-0.53 (-1.07, 0.01)
Used face protection[b] consistently	713 (100)	-0.08 (-0.24, 0.09)	713 (100)	-0.01 (-0.45, 0.43)

[a]Consistently defined as ≥80% of the time at work.
[b]Face protection = either reported mask or eye protection.

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the personal protective equipment question and a Piko-1 spirometry test result.

Table 2.13. Cross tabulations of personal protective equipment (PPE) and reported work exposures within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	Body protection, n (%)			Face protection, n (%)		
	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)
Barn conditions score[a]						
0	53 (15)	298 (85)		124 (35)	226 (65)	
1	74 (33)	148 (67)	**<0.001**	128 (58)	92 (42)	**<0.001**
2 or more	21 (16)	112 (84)		88 (66)	45 (34)	
Cleaning score[b]						
0	57 (25)	172 (75)		112 (50)	114 (50)	
1	57 (31)	125 (69)	**<0.001**	94 (52)	88 (48)	0.703
2 or more	41 (13)	272 (87)		149 (48)	163 (52)	
Pig contact score[c]						
0	84 (27)	223 (73)		153 (50)	151 (50)	
1	28 (12)	203 (88)	**<0.001**	97 (42)	134 (58)	**0.005**
2	42 (23)	142 (77)		106 (58)	77 (42)	
Score components[d]						
0 or 1	40 (25)	121 (75)		68 (43)	92 (58)	
2 or 3	66 (22)	233 (78)	0.158	136 (46)	161 (54)	**0.039**
4, 5, or 6	40 (17)	193 (83)		127 (55)	106 (45)	
Number of times washed hands per shift						
Tertile 1 (0-6)	70 (23)	239 (77)		168 (55)	140 (45)	
Tertile 2 (7-10)	70 (21)	267 (79)	0.531	140 (42)	193 (58)	**0.001**
Tertile 3 (11-50)	14 (21)	68 (83)		49 (60)	33 (40)	

[a]Sum of extreme temperature (yes=1, no=0), extreme malodor (yes=1, no=0), extreme dust (yes=1, no=0), vents off (yes=1, no=0), and a new herd entering the barn(s) (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), used pesticides (yes=1, no=0), pressure washed (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs shots (yes=1, no=0) and gave pigs medicine (yes=1, no=0)
[d]Sum of all above components, with a possible total of 0 to 11.

Table 2.14. Cross tabulations of personal protective equipment (PPE) use and reported symptoms within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	Body protection, n (%)			Face protection, n (%)		
	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)
At least one respiratory symptom[a]						
No	148 (21)	541 (79)	0.709	341 (50)	342 (50)	0.555
Yes	8 (19)	34 (81)		19 (45)	23 (55)	
At least one symptom interfered with sleep[b]						
No	146 (21)	544 (79)	0.478	344 (50)	340 (50)	0.117
Yes	4 (15)	22 (85)		9 (35)	17 (65)	
Sneezing						
No	152 (21)	564 (79)	0.919	357 (50)	353 (50)	0.059
Yes	4 (22)	14 (78)		5 (28)	13 (72)	
Headache						
No	151 (21)	568 (79)	0.248	356 (50)	357 (50)	0.447
Yes	5 (33)	10 (67)		6 (40)	9 (60)	
Eye or nose symptoms						
No	153 (21)	567 (79)	0.987	356 (50)	358 (50)	0.604
Yes	3 (21)	11 (79)		6 (43)	8 (57)	

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

Table 2.15. Crude longitudinal relationship between reported personal protective equipment (PPE) and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression.

In the past week	FEV$_1$ (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	712 (100)	Ref (0.0)	0.131	712 (100)	Ref (0.0)	**0.006**
Face protection consistently		-0.27 (-0.55, 0.01)			**-0.90 (-1.64, -0.15)**	
Body protection consistently		**-0.40 (-0.68, -0.12)**			**-1.26 (-2.01, -0.50)**	
Face + body protection consistently		**-0.43 (-0.74, -0.12)**			**-0.97 (-1.79, -0.14)**	

[a]Consistently defined as ≥80% of the time at work.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the PPE question and a Piko-1 spirometry test result.

Table 2.16. Crude longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression and stratified by experiencing dustiness or odor in the past week.

In the past week	**Experienced some form of dustiness or odor[b]**					
	FEV_1 (L)			**PEFr (L/s)**		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither PPE consistently[a]	343 (87)	Ref (0.0)	0.470	343 (87)	Ref (0.0)	0.319
Face protection consistently		-0.35 (-0.75, 0.05)			-0.90 (-1.89, 0.10)	
Body protection consistently		**-0.47 (-0.87, -0.06)**			**-1.64 (-2.65, -0.62)**	
Face + body protection consistently		**-0.65 (-1.10, -0.19)**			**-1.94 (-3.06, -0.81)**	

In the past week	**Did not experience some form of dustiness or odor[b]**					
	FEV_1 (L)			**PEFr (L/s)**		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither PPE consistently[a]	349 (85)	Ref (0.0)	0.250	349 (85)	Ref (0.0)	0.108
Face protection consistently		-0.19 (-0.72, 0.35)			-0.79 (-2.29, 0.72)	
Body protection consistently		-0.43 (-1.00, 0.14)			-0.76 (-2.38, 0.85)	
Face + body protection consistently		-0.28 (-0.88, 0.31)			-0.22 (-1.89, 1.46)	

[a]Consistently defined as ≥80% of the time at work.
[b]Any of the following: extreme temperature, extreme malodor, extreme dust, vents off, or a new herd entering the barns.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with a response to the exposure and PPE questions and a Piko-1 spirometry test result.

Table 2.17. Crude longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression and stratified by cleaning activities in the past week.

In the past week	**Performed a cleaning activity[b]**					
	FEV_1 (L)			**PEFr (L/s)**		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither PPE consistently[a]	481 (91)	Ref (0.0)	0.792	407 (83)	Ref (0.0)	0.094
Face protection consistently		-0.18 (-0.53, 0.18)			-0.74 (-1.65, 0.17)	
Body protection consistently		-0.30 (-0.67, 0.07)			**-1.27 (-2.23, -0.30)**	
Face + body protection consistently		**-0.42 (-0.82, -0.02)**			**-1.12 (-2.15, -0.09)**	
In the past week	**Did not perform a cleaning activity[b]**					
	FEV_1 (L)			**PEFr (L/s)**		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither PPE consistently[a]	225 (75)	Ref (0.0)	**0.003**	225 (75)	Ref (0.0)	**<0.001**
Face protection consistently		**-0.83 (-1.47, -0.20)**			**-2.95 (-4.68, -1.22)**	
Body protection consistently		**-1.19 (-1.86, -0.52)**			**-3.31 (-5.14, -1.47)**	
Face + body protection consistently		**-0.91 (-1.63, -0.20)**			**-2.25 (-4.20, -0.29)**	

[a]Consistently defined as ≥80% of the time at work.
[b]Did not report any of the following: used cleaning chemicals and/or pesticides, pressure washed or used a torch.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with a response to the exposure and PPE questions and a Piko-1 spirometry test result.

Table 2.18. Crude longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression and stratified by having pig contact in the past week.

In the past week	Had pig contact[b]					
		FEV1 (L)			PEFr (L/s)	
	visits (workers)	ß (95% CI)	p for interaction	visits (workers)	ß (95% CI)	p for interaction
Neither protection consistently[a]		Ref (0.0)			Ref (0.0)	
Face protection consistently	407 (83)	-0.21 (-0.60, 0.19)	0.484	407 (83)	**-1.14 (-2.16, -0.12)**	**0.015**
Body protection consistently		-0.43 (-0.86, 0.005)			**-2.20 (-3.22, -0.99)**	
Face + body protection consistently		**-0.48 (-0.92, -0.03)**			**-1.82 (-2.97, -0.67)**	
	Did not have pig contact[b]					
In the past week		FEV1 (L)			PEFr (L/s)	
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]		Ref (0.0)			Ref (0.0)	
Face protection consistently	297 (75)	**-0.53 (-0.97, -0.08)**	0.067	297 (75)	-1.21 (-2.45, 0.02)	**0.042**
Body protection consistently		**-0.47 (-0.88, -0.05)**			-0.94 (-2.09, 0.21)	
Face + body protection consistently		**-0.52 (-1.02, -0.01)**			-0.70 (-2.09, 0.68)	

[a]Consistently = ≥80% of the time at work
[b] Did not report giving pigs shots or medicine.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with a response to the exposure and PPE questions and a Piko-1 spirometry test result.

Table 2.19. Crude longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression and stratified by having pig contact in the past week.

In the past week	Two or more scored activities[b]					
	FEV$_1$ (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	460 (90)	Ref (0.0)	0.963	460 (90)	Ref (0.0)	0.171
Face protection consistently		-0.14 (-0.50, 0.23)			-0.66 (-1.59, 0.27)	
Body protection consistently		-0.21 (-0.61, 0.19)			**-1.48 (-2.49, -0.46)**	
Face + body protection consistently		-0.36 (-0.77, 0.05)			**-1.39 (-2.44, -0.33)**	
In the past week	**Less than two scored activities[b]**					
	FEV$_1$ (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	219 (76)	Ref (0.0)	**0.006**	219 (76)	Ref (0.0)	**<0.001**
Face protection consistently		**-0.75 (-1.36, -0.13)**			**-2.57 (-4.21, -0.92)**	
Body protection consistently		**-0.96 (-1.58, -0.33)**			**-2.57 (-4.26, -0.88)**	
Face + body protection consistently		**-0.73 (-1.42, -0.03)**			-1.72 (-3.58, 0.15)	

[a]Consistently = ≥80% of the time at work

[b]Possible activities include:extreme temperature (yes=1, no=0), extreme malodor (yes=1, no=0), extreme dust (yes=1, no=0), vents off (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), used cleaning chemicals (yes=1, no=0), used pesticides (yes=1, no=0), pressure washed (yes=1, no=0), and used a torch (yes=1, no=0), gave pigs shots (yes=1, no=0) and gave pigs medicine (yes=1, no=0).

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with a response to the exposure and PPE questions and a Piko-1 spirometry test result.

Table 2.20. Crude longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression and stratified by working in different lifestage barns as reported at baseline.

In the past week	Works only in sow, nursery, and/or farrow barns					
	FEV1 (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	342 (46)	Ref (0.0)	0.008	342 (46)	Ref (0.0)	<0.001
Face protection consistently		-0.33 (-0.66, 0.01)			**-1.22 (-2.17, -0.27)**	
Body protection consistently		**-1.05 (-1.51, -0.59)**			**-3.30 (-4.61, -1.99)**	
Face + body protection consistently		**-0.80 (-1.29, -0.32)**			**-2.28 (-3.66, -0.91)**	

In the past week	Works only in feeder or finisher barns					
	FEV1 (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	164 (23)	Ref (0.0)	0.968	164 (23)	Ref (0.0)	0.720
Face protection consistently		-0.35 (-1.27, 0.57)			-0.19 (-2.45, 2.07)	
Body protection consistently		-0.18 (-0.97, 0.61)			-0.14 (-2.08, 1.80)	
Face + body protection consistently		-0.51 (-1.40, 0.38)			-0.74 (-2.92, 1.44)	

[a]Consistently = ≥80% of the time at work

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with a response to the exposure and PPE questions and a Piko-1 spirometry test result.

FIGURES

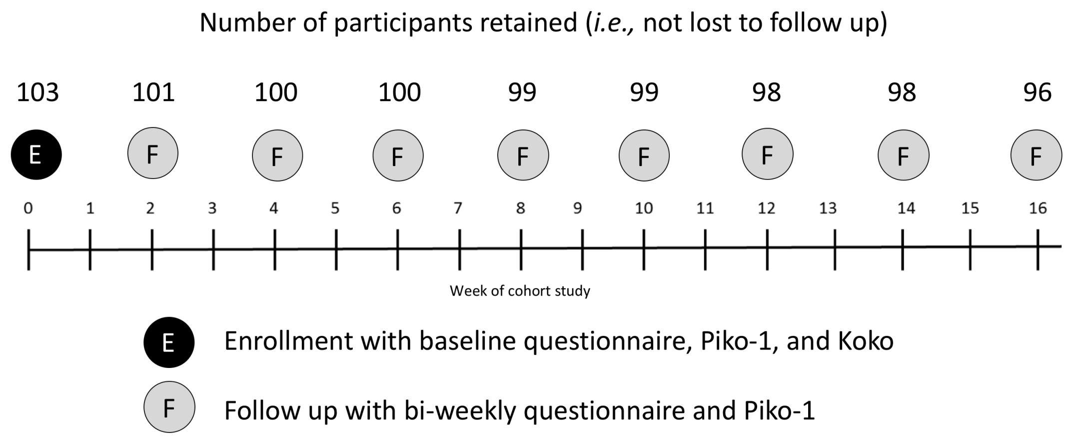

Figure 2.1. Sampling scheme and loss-to-follow-up between the baseline and bi-weekly study visits within a cohort of industrial hog operation (IHO) workers, North Carolina, 2013-2014.

SUPPLEMENTAL MATERIAL

Table S2.1. Descriptive statistics of spirometry measurements restricted to those with three tries recorded and the best two within 0.15L for FEV_1 or 0.67L for PEFr at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

			Predicted values[a]				
Characteristic	**n**	**Mean (SD)**	**n**	**Mean (SD)**	**n**	**% (SD)**	**R^2 for Piko-1 and Koko based on mean measurement**
Koko							
FEV_1 (L)	60	3.3 (0.8)	58	3.4 (0.7)	58	97.2 (17.9)	-
PEFr (L/s)	38	6.7 (2.1)	36	4.8 (0.4)	36	144.1 (37.1)	-
FVC (L)	56	3.9 (0.9)	55	4.1 (0.8)	55	95.1 (16.6)	-
FEV_1/FVC	50	0.8 (0.1)	49	0.8 (0.0)	49	100.7 (6.1)	-
Piko-1							
FEV_1 (L)	55	2.8 (0.7)	52	3.3 (0.8)	52	88.7 (20.0)	0.92
PEFr (L/s)	52	6.6 (2.2)	49	4.9 (0.5)	49	137.6 (42.2)	0.79

[a]As predicted using Hankinson 1999 reference values.

Table S2.2a. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1			% Predicted FVC		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	63	1.02 (-8.64, 10.69)		63	-0.75 (-9.64, 8.14)	
Drawn pigs blood	63	5.51 (-16.92, 27.94)		63	1.85 (-15.25, 18.94)	
Handled pig manure	63	3.56 (-5.62, 12.74)		63	3.98 (-5.97, 13.94)	
Applied pesticides in or around the barns	63	0.51 (-7.13, 8.16)		63	-4.22 (-12.68, 4.25)	
Washed work clothes with household laundry	62	4.12 (-7.67, 15.91)		62	2.48 (-9.20, 14.16)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	61	-0.15 (-9.09, 8.79)		61	-0.74 (-9.32, 7.85)	
Work exclusively in feeder and/or finisher barns	61	-3.23 (-12.47, 6.01)		61	-1.41 (-10.82, 8.00)	
Always wear a mask and bodysuit and eye protection	62	4.05 (-6.50, 14.61)		62	4.05 (-8.56, 16.67)	
Worked 7 days per week	63	0.01 (-8.71, 8.72)		63	0.42 (-8.94, 9.78)	
100% of time at work spent in direct contact with hogs	63	-6.24 (-14.90, 2.42)		63	-6.78 (-15.24, 1.67)	
Years worked on any IHO						
Tertile 1 (1-5 years)	59	Ref (0.0)	0.088	59	Ref (0.0)	0.059
Tertile 2 (6-10 years)		-6.99 (-16.66, 2.68)			-5.66 (-15.86, 4.55)	
Tertile 3 (11-27 years)		-8.97 (-19.35, 1.42)			-10.45 (-21.33, 0.43)	
Percent of life working on any IHO						
Tertile 1 (2.4-11.6%)	59	Ref (0.0)	0.570	59	Ref (0.0)	0.537
Tertile 2 (11.7-26.3%)		-9.80 (-20.84, 1.24)			-4.26 (-16.49, 7.98)	
Tertile 3 (26.4-51.9%)		-4.15 (-14.27, 5.97)			-3.89 (-15.29, 7.50)	

[a]Performed on a Koko spirometer

Table S2.2b. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	62	**-24.15 (-48.01, -0.30)**		63	2.79 (-0.45, 6.02)	
Drawn pigs blood	62	6.31 (-19.17, 31.80)		63	1.63 (-3.50, 6.75)	
Handled pig manure	62	4.78 (-15.85, 25.40)		63	-0.91 (-4.33, 2.51)	
Applied pesticides in or around the barns	62	11.07 (-11.05, 33.19)		63	**5.15 (1.68, 8.61)**	
Washed work clothes with household laundry	61	16.92 (-8.04, 41.87)		62	0.75 (-3.80, 5.31)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	60	-3.91 (-24.42, 16.60)		61	0.98 (-2.24, 4.20)	
Work exclusively in feeder and/or finisher barns	60	-1.85 (-22.25, 18.56)		61	-1.65 (-6.33, 3.02)	
Always wear a mask and bodysuit and eye protection	61	-4.51 (-44.37, 35.34)		62	-0.41 (-4.52, 3.70)	
Worked 7 days per week	62	-10.46 (-31.72, 10.80)		63	-0.41 (-4.06, 3.24)	
100% of time at work spent in direct contact with hogs	62	6.92 (-10.91, 24.75)		63	0.92 (-2.60, 4.44)	
Years worked on any IHO				59		
Tertile 1 (1-5 years)	58	Ref (0.0)	0.548		Ref (0.0)	0.696
Tertile 2 (6-10 years)		-6.72 (-31.20, 17.76)			-1.62 (-7.26, 4.03)	
Tertile 3 (11-27 years)		-8.86 (-38.26, 20.54)			0.72 (-2.61, 4.05)	
Percent of life working on any IHO				59		
Tertile 1 (2.4-11.6%)	58	Ref (0.0)	0.971		Ref (0.0)	0.715
Tertile 2 (11.7-26.3%)		-9.00 (-40.01, 22.01)			**-6.13 (-11.57, -0.68)**	
Tertile 3 (26.4-51.9%)		-0.49 (-32.23, 31.24)			-1.54 (-5.42, 2.34)	

[a]Performed on a Koko spirometer

Table S2.2c. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1 [a]			% Predicted PEFr [a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	70	3.79 (-8.26, 15.85)		72	4.96 (-17.11, 27.03)	
Drawn pigs blood	70	-0.39 (-14.81, 14.03)		72	-4.92 (-23.96, 14.13)	
Handled pig manure	69	-2.93 (-13.69, 7.82)		71	-12.51 (-34.58, 9.56)	
Applied pesticides in or around the barns	70	-1.14 (-9.44, 7.16)		72	-4.60 (-22.28, 13.09)	
Washed work clothes with household laundry	69	-1.12 (-14.96, 12.72)		71	7.53 (-15.90, 30.97)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	68	-5.79 (-15.06, 3.48)		70	-13.20 (-31.05, 4.66)	
Work exclusively in feeder and/or finisher barns	68	1.82 (-6.93, 10.57)		70	3.05 (-12.33, 18.43)	
Always wear a mask and bodysuit and eye protection	69	5.07 (-3.93, 14.07)		71	-0.57 (-19.60, 18.46)	
Worked 7 days per week	70	1.33 (-6.99, 9.64)		72	**-18.78 (-33.89, -3.66)**	
100% of time at work spent in direct contact with hogs	70	-5.92 (-15.63, 3.78)		72	-0.89 (-19.42, 17.64)	
Years worked on any IHO						
Tertile 1 (1-5 years)	64	Ref (0.0)	0.345	67	Ref (0.0)	0.378
Tertile 2 (6-10 years)		5.41 (-7.12, 17.94)			9.83 (-11.41, 31.06)	
Tertile 3 (11-27 years)		-5.87 (-17.21, 5.48)			-10.81 (-32.74, 11.12)	
Percent of life working on any IHO						
Tertile 1 (2.4-11.6%)	64	Ref (0.0)	0.224	65	Ref (0.0)	0.355
Tertile 2 (11.7-26.3%)		-7.04 (-19.78, 5.69)			-13.53 (-38.77, 11.70)	
Tertile 3 (26.4-51.9%)		-7.16 (-18.29, 3.97)			-12.51 (-37.89, 12.86)	

[a]Performed on a Piko-1 spirometer

Table S2.3a. Hour of test (continuous), current cigarette smoking (binary), and interviewer (dummy) adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1[a]		**% Predicted FVC[a]**		**% Predicted PEFr[a]**		**% Predicted FEV_1/FVC[a]**	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	62	6.85 (-3.32, 17.02)	62	5.57 (-3.69, 14.83)	61	6.99 (-10.74, 24.72)	62	0.07 (-3.11, 3.24)
Any allergies	63	**-14.72 (-26.55, -2.90)**	63	**-14.26 (-26.07, -2.46)**	62	**-24.86 (-46.37, -3.35)**	63	0.07 (-4.04, 4.19)
Doctor-diagnosed asthma	63	-9.71 (-28.14, 8.72)	63	-8.32 (-27.10, 10.47)	62	3.31 (-27.40, 34.02)	63	-1.56 (-4.65, 1.53)

[a]Performed on a Koko spirometer

Table S2.3b. Hour of test (continuous), current cigarette smoking (binary), and interviewer (dummy) adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level.

	% Predicted FEV_1[a]		**% Predicted PEFr[a]**	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	69	3.28 (-5.70, 12.27)	72	4.71 (-9.39, 18.80)
Any allergies	70	-6.75 (-25.71, 12.21)	72	12.72 (-14.02, 39.47)
Doctor-diagnosed asthma	70	-13.32 (-29.98, 3.34)	73	-3.05 (-22.06, 15.96)

[a]Performed on a Piko-1 spirometer

Table S2.4. Hour of test (dummy), month of test (dummy), smoked in the past 12 hours (binary), and interviewer (dummy)-adjusted relationship between reported exposure scores and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression.

In the past week	FEV$_1$ (L) visits (workers)*	FEV$_1$ (L) ß (95% CI)	FEV$_1$ (L) p for trend	PEFr (L/s) visits (workers)*	PEFr (L/s) ß (95% CI)	PEFr (L/s) p for trend
Dustiness score[a]						
0	684 (99)	Ref (0.0)	0.354	684 (99)	Ref (0.0)	0.271
1		0.02 (-0.14, 0.18)			0.06 (-0.37, 0.48)	
2		-0.17 (-0.38, 0.04)			-0.26 (-0.82, 0.30)	
3 or 4		0.03 (-0.32, 0.37)			-0.39 (-1.29, 0.51)	
Cleaning score[b]						
0	708 (99)	Ref (0.0)	0.313	708 (99)	Ref (0.0)	0.511
1		0.04 (-0.13, 0.21)			-0.12 (-0.57, 0.33)	
2		0.05 (-0.13, 0.24)			0.03 (-0.45, 0.51)	
3 or 4		0.12 (-0.10, 0.33)			0.18 (-0.39, 0.75)	
Pig contact score[c]						
0	705 (100)	Ref (0.0)	0.221	705 (100)	Ref (0.0)	0.319
1		-0.09 (-0.26, 0.08)			-0.26 (-0.71, 0.19)	
2		-0.11 (-0.30, 0.07)			-0.25 (-0.72, 0.23)	
Score components[d]						
0 or 1	672 (99)	Ref (0.0)	0.906	672 (99)	Ref (0.0)	0.756
2 or 3		-0.05 (-0.23, 0.13)			0.12 (-0.34, 0.59)	
4 to 6		-0.01 (-0.21, 0.19)			0.11 (-0.41, 0.63)	
PPE score[e,f]						
0	703 (100)	Ref (0.0)	0.052	703 (100)	Ref (0.0)	0.281
1		**-0.29 (-0.55, -0.03)**			**-0.85 (-1.55, -0.15)**	
2		**-0.44 (-0.77, -0.11)**			**-0.94 (-1.81, -0.06)**	

3		**-0.42 (-0.78, -0.05)**			-0.80 (-1.78, 0.18)	
Number of times washed hands per shift						
Tertile 1 (0-6)	707 (100)	Ref (0.0)	0.861	707 (100)	Ref (0.0)	0.102
Tertile 2 (7-10)		-0.03 (-0.18, 0.13)			0.13 (-0.27, 0.53)	
Tertile 3 (11-50)		0.04 (-0.18, 0.27)			0.54 (-0.05, 1.13)	

[a]Sum of extreme temperature (yes=1, no=0), extreme malodor (yes=1, no=0), extreme dust (yes=1, no=0), vents off (yes=1, no=0), and a new herd entering the barn(s) (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), used pesticides (yes=1, no=0), pressure washed (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs shots (yes=1, no=0) and gave pigs medicine (yes=1, no=0)
[d]Summation of binary (0=0, >0=1) to a,b, and/or c
[e]Sum of consistently (≥80% of the time at work) wore the following: mask (yes=1, no=0), glasses (yes=1, no=0), and bodysuit/coveralls (yes=1, no=0)
[f]PPE = personal protective equipment

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the exposure question and a Piko-1 spirometry test result.

Table S2.5. Hour of test (dummy), month of test (dummy), smoked in the past 12 hours (binary), and interviewer (dummy)-adjusted relationship between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	visits (workers)*	OR (95% CI)	visits (workers)*	OR (95% CI)
Experienced some form of dustiness or odor[a]	691 (99)	-0.02 (-0.17, 0.14)	691 (99)	-0.04 (-0.45, 0.36)
Performed a cleaning activity[b]	711 (99)	0.05 (-0.10, 0.20)	711 (99)	-0.01 (-0.41, 0.39)
Had pig contact[c]	708 (100)	-0.10 (-0.25, 0.06)	708 (100)	-0.24 (-0.65, 0.17)
Performed two or three of the above[d]	679 (99)	0.03 (-0.13, 0.19)	679 (99)	-0.02 (-0.44, 0.40)
Used any protection consistently[e]	703 (100)	**-0.30 (-0.56, -0.04)**	703 (100)	**-0.85 (-1.55, -0.16)**
Handwashing at least 8 times per shift[f]	707 (100)	0.05 (-0.10, 0.19)	707 (100)	0.21 (-0.16, 0.59)
Worked seven days	726 (100)	-0.05 (-0.19, 0.09)	726 (100)	0.16 (-0.20, 0.52)
Worked at least 45 hours	717 (100)	-0.05 (-0.19, 0.08)	717 (100)	0.21 (-0.15, 0.57)

[a]Reported at least one of the following: extreme temperature, extreme malodor, extreme dust, vents off, or a new herd entering the barns
[b]Reported at least one of the following: used cleaning chemicals and/or pesticides, pressure washed or used a torch
[c]Reported at least one of the following: gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f]8 is the median

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the exposure question and a Piko-1 spirometry test result.

Table S2.6. Adjusted longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression.

	FEV_1 (L)		**PEFr (L/s)**	
	visits (workers)*	ß (95% CI)	visits (workers)*	ß (95% CI)
Used coveralls/ full bodysuit consistently[a]	708 (100)	**-0.33 (-0.57, -0.08)**	708 (100)	**-0.67 (-1.32, -0.02)**
Used face protection consistently	705 (100)	-0.13 (-0.32, 0.05)	705 (100)	-0.21 (-0.70, 0.29)

[a]Consistently = ≥80% of the time at work

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the PPE question and a Piko-1 spirometry test result.

Table S2.7. Adjusted longitudinal relationship between reported personal protective equipment and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using fixed-effects regression.

	FEV$_1$ (L)			PEFr (L/s)		
	visits (workers)*	ß (95% CI)	p for interaction	visits (workers)*	ß (95% CI)	p for interaction
Neither protection consistently[a]	703 (100)	Ref (0.0)		703 (100)	Ref (0.0)	
Face protection consistently		-0.19 (-0.49, 0.11)			-0.66 (-1.46, 0.14)	
Body protection consistently		**-0.39 (-0.70, -0.09)**			**-1.06 (-1.88, -0.24)**	
Face + body protection consistently		**-0.59 (-1.11, -0.06)**	**0.029**		**-1.72 (-3.12, -0.31)**	**0.017**

[a]Consistently = ≥80% of the time at work

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the PPE question and a Piko-1 spirometry test result.

Table S2.8. Crude relationship between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression.

In the past week	FEV$_1$ (L)		PEFr (L/s)	
	obs. (groups)*	ß (95% CI)	obs. (groups)*	ß (95% CI)
At least one respiratory symptom[a]	732 (100)	**-0.34 (-0.58, -0.10)**	732 (100)	**-0.98 (-1.61, -0.35)**
At least one symptom interfered with sleep[b]	717 (100)	-0.24 (-0.54, 0.06)	717 (100)	**-0.87 (-1.66, -0.07)**
Sneezing	732 (100)	-0.26 (-0.64, 0.13)	732 (100)	-0.81 (-1.83, 0.21)
Headache	732 (100)	-0.24 (-0.63, 0.15)	732 (100)	-0.94 (-1.97, 0.08)
Eye or nose irritation	732 (100)	-0.11 (-0.52, 0.29)	732 (100)	0.19 (-0.88, 1.26)

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a Piko-1 spirometry test result.

CHAPTER 3

Piloting the use of mobile devices in community-driven research to assess occupational and environmental exposures from industrial hog operations in rural eastern North Carolina

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ABSTRACT

Background: Workers in and community residents living proximal to industrial hog operations (IHOs) want to know the extent to which airborne pig waste from IHOs impact their household environment and health-related quality of life. With advances in molecular source tracking technology such questions can be answered through measurement of pig-specific fecal bacterial source tracking markers (*e.g.,* Pig-2-Bac) and livestock-associated bacteria (*e.g*., *Staphylococcus aureus*) in the air, on household surfaces, and in nasal swab samples from residents.

Objectives: This paper sought to assess the feasibility, practicability, capacity-building potential, and data quality and completeness of novel technology and microbial source-tracking marker use in a community-driven research (CDR) pilot to assess household environmental exposures to IHOs. Data quality and completeness were outcomes used to assess success of the study. Key lessons were identified to inform future, expanded research.

Methods: A pilot study was conducted that followed the tenets of community-driven research (CDR) and worked through an iterative process to answer questions of at-home exposure to pig fecal waste and to address the flexible, rapid-response data collection capacity building goals of the community. From November 2017 to April 2018, community organizers collected air, household surface, and nasal swab samples, as well as questionnaires, at households with *vs.* without an IHO worker living in the home, and at varying distances from IHOs. Data were assessed for completeness and quality, defined as *missingness* (a measure of completeness), *incorrect data type* (a measure of validity), *out of range* (a measure of validity), and *outliers* (a measure of accuracy) by two independent reviewers.

Results: Each week, two to three households were sampled for a total of 49 households (26 IHO worker and 23 community referent households enrolled). Of those enrolled, 18 IHO-employed households (n=36 participants) and 20 community referent households (n=41 participants) were deemed eligible after data review—loss of eight IHO and three community referent households (n=8 IHO workers; n=8 IHO worker children; n=3 community referent workers; and n=3 community referent children). In total, 18,469 of 18,932 (98%) required questions were complete and 18,912 of 18,932 (100%) were the correct data type (*e.g.,* a numeric response for a question about participant age) and were not out of range (*e.g.,* an adult's age between 18 and 100). Using community-defined, appropriate testing protocols, academics were able to help design a pilot study to address questions of differences in at-home exposure to bacteria relative to distance from IHOs and build capacity for the community organization.

Conclusions: Novel exposure assessment (molecular source-tracking) and survey data collection (mobile device/tablet), as well as planning techniques (defining a data collection protocol with community research partners, scaling back tests to a practical level, and the use of appropriate technology) were employed to assess hog waste exposure at the homes of IHO workers and community residents, with high data quality and completeness from eligible participants.

INTRODUCTION

Community-driven research (CDR) brings together academics, community leaders, and concerned citizens to employ science to solve problems the public faces. A key tenet of this approach is that each stakeholder group shares equally in every step from design to dissemination of the work. CDR requires different research strategies and skills than traditional epidemiologic research. As of 2004, only 30 CDR non-interventional studies were published, with only five of those moving beyond problem identification to risk factor assessments and only two examining prevalence of disease. Further, only four collaborations specifically stated that increasing community capacity or engendering empowerment was the major objective.[171]

Gaps in the literature not only stem from a dearth of CDR publications, but also many unanswered questions remain regarding airborne exposure from industrial hog operations (IHOs) and how hog waste may impact community health. While publications have attempted to determine a “safe” distance from IHO plumes, differences in distances at which bacteria and gases can be recovered have been reported.[88,172]

With the contentious political environment surrounding hog waste and advances in molecular source tracking, there is a need for improved measures of community exposure to swine-specific wastes and to determine associations between presence of such swine-specific wastes and prevalence of health outcomes. Communities are empowered by these scientific advancements and can benefit from continued study.

In 2005, academics at University of North Carolina at Chapel Hill (UNC) partnered with the Rural Empowerment Association for Community Help (REACH) for the first time to explore environmental justice issues facing residents in rural southeastern

North Carolina.[109,173-175] Since then, the relationship has continued with various exposures examined through a CDR framework. In 2013, researchers at UNC and Johns Hopkins University (JHU) undertook a study with REACH to examine the impact industrial hog operations (IHOs) have on community health. A variety of studies have come from this research project, enlightening researchers and providing answers to the community about exposures, enabling them to advocate for policy change, and building capacity for future work both through knowledge and the acquisition of scientific instruments and tools. Of these community-driven research questions, researchers and the community now better understand the impact of *Staphylococcus aureus* on skin and soft-tissue infections,[71,116] how IHO worker mask usage can modify that relationship [Nadimpalli, 2018], how on-IHO conditions impact physical worker health and increase respiratory symptoms [unpublished Coffman, 2018], and which modifiable factors operations or IHO workers can employ to protect the health of those in close day-to-day contact with pigs [unpublished Coffman, 2018].

The politics and policies surrounding these operations also drive research. For example, during a 2017 North Carolina House debate regarding House Bill 467 Rep. Jimmy Dixon (District 4-R) (Duplin and Wayne counties) remarked that:

> "'These allegations are at best exaggerations and at worst outright lies," Dixon said of the concerns people living near hog farms have continually expressed. "Spraying effluent on people's houses and cars, that does not exist. When the final chapter is written on these cases, we'll see the people being represented are being prostituted for money.'"[176]

Not only has Mr. Dixon made claims that either need to be substantiated or refuted with scientific data, but larger gaps in knowledge also exist about how emissions from CAFOs can impact community health[177] and research of this nature has been identified as much needed.[13]

The goal of this paper is to report upon aspects of study design, data completeness and quality, and lessons learned from a community-driven pilot study of microbial source tracking of IHO-related air pollution at homes proximal to IHOs. Discussed is the processes of decision-making, data collection, and data quality review related to: (1) finalizing of research questions and design the pilot study; (2) training of community organizers in data collection procedures; (3) collection of data; and (4) reviewing of data completeness and quality.

LESSONS LEARNED

Distilling research questions down to those that are practical and answerable

A critical component of this study was the vetting of each research question, balancing scientific rigor with feasibility, and without falsely raising expectations for the community. REACH initially envisioned deploying a rapid response team by when neighbors observed spraying or malodor. But based on scientific knowledge and statistical power, employing a cross-sectional design with comparison groups was ultimately agreed upon. These questions were deemed more rigorous and benefitted from the ability to have scheduled home visits.

Of particular importance to the community and testable hypotheses were that: (1) more hog fecal waste would be found outside homes than inside; (2) more hog fecal waste would be found on and in homes closer to IHOs than farther away; (3) more hog fecal waste would be found on surfaces inside homes where an IHO worker lived versus those without an IHO worker given the homes were at similar distances from an operation; and (4) those living closer to IHOs would have more health symptoms than those living further away.

Delineating roles and responsibilities of each partner

Based on the principles of empowerment and equal rights, the Rural Empowerment Association for Community Help (REACH) was founded in 2002 and is run by community leaders.[178] Having a well-established community partner is one of the strengths of this collaboration. They acutely understand the politics of the area and can navigate situations based on experience, drawing on past successes and failures. Monthly, they hold open-door meetings that people from the community attend to discuss local issues, remedies, and results from on-going data collection.

Face-to-face meetings were held to explore the roles and responsibilities of each partner group. Collectively, it was decided that the academic partners would present data collection options, secure funding, submit updated institutional review board (IRB) paperwork, conduct quality control of data, and perform data analysis. REACH remained responsible to define study materials, collect data, transport materials, and disseminate results to the community.

Drafting a research protocol to be followed in the field

Previous community-driven research with REACH noted the need for better training and more frequent input on data collection practices from researchers.[179] Thus, training of both academic and community organizers was undertaken three times before sampling was conducted to ensure scientific rigor was achieved and data collection techniques remained appropriate.

The first in-person session was held at REACH's office in Warsaw, N.C. Academics from JHU and UNC delivered possible research tools: sampling equipment and printouts of tests that had been used in prior work as well as some options that were new (all items from **Figure 3.2**). JHU arrived with a veterinarian team to discuss gathering *Staphylococcus aureus* pet carriage data and brought a dog to the office to demonstrate how sampling of a live animal could be conducted. After viewing all the items, REACH offered feedback on what would be accepted in the community. Together, the team decided what would be used to collect air and dust samples.

The team of academics and community partners together decided that researchers would need more discrete sampling equipment, faster protocols, and less intrusive environmental testing sites than those employed in prior legal work. For example, in Baltimore one research group vacuums indoor surfaces to determine the composition of household dust, including in between bed sheets.[180] The REACH team felt such an intimate level of data collection would be a deterrent to household participation because it was too personal and might embarrass workers who do not have a bed, let alone sheets.

Many of the households in this area are below the poverty line and live in mobile homes, some without electricity. The lack of electricity and cost of monthly bills was taken into careful consideration when selecting equipment for sampling. One device, a high-volume air sampler that researchers envisioned being run for eight hours at a time from a household outlet, was deemed too costly and conspicuous for this community. In the past, REACH had used low-volume button aerosol samplers [SKC, Eighty Four, Pennsylvania] button samplers running for eight hours. While small and battery-operated, these devices involve precise assembly and cannot come pre-sterilized. Further, they must run for a longer period of time compared with high-volume samplers, as they can only draw a maximum of 4L of air per minute. Instead of the button aerosol samplers, the team opted to purchase a new battery-operated high-volume (50L/min) sampler (AirPort MD8, Sartorius, Goettingen, Germany) that comes with pre-sterilized filters.

A key factor in the research design was time. Executing every element of the expanded options would have taken too long for both participants and organizers. Another was privacy. REACH members raised concerns about neighbors potentially recognizing that a specific household was participating in a study. IHO workers fear employer reprimands for participating in anything perceived as anti-IHO research, and having scientific equipment assembled and in view of passersby can create many problems. The final sampling protocol and decisions for research in this specific community can be seen in **Figure 3.2**.

After research design adjustments were made and community organizers reviewed protocols, a second in-person team meeting took place in North Carolina. It consisted of a retraining of only the selected equipment and time for community researchers to ask questions. The third face-to-face meeting allowed for the REACH team to demonstrate the final protocol through dry sampling runs, as REACH would perform all data collection.

Throughout the face-to-face sessions, and additional weekly phone calls, all parties remained flexible to tweak protocols and to add items as needed. For example, cheek swabs require two minutes of the participant rubbing a sponge on the inside of the mouth to collect saliva. Instead of asking the field team to use a smart phone or watch to time the maneuver, inexpensive plastic sand timers were purchased (**Figure 3.2**). These had the benefit of showing participants how close they were to completing the task. It was also decided to print step-by-step instructions and tape them on each instrument with large luggage tags so that instructions were handy in case a researcher needed a quick reminder of how to operate the device.

One of the main goals of this project was to build capacity. At each training session academic partners not only demonstrated how a technology could be used but also explained why it was being used. REACH has been able to apply this knowledge in other work and its members are now better-versed in the science behind the tools.

Distributing resources to the community partners

Funding was secured to provide REACH with two new iPads (Apple Inc., Cupertino, California), weather stations, and GPS units for data collection but the partnership was unable to purchase some of the more expensive air monitoring equipment such as those devices found in the large stationary trailer used in past work[174] (**Figure**

3.2). Funding was also obtained to pay REACH's community organizers to undertake data collection and for participant incentives.

Defining study materials that meet the needs of both partners

While capacity building is critical for REACH (*i.e.,* learning new technologies and data collection tools) researchers often found themselves reverting to older, low-tech choices (*e.g.,* sand timers, luggage tags, print-offs of mask pictures). In resource-limited situations, this may be an advantage. It was also found that "plug and play"-type data collection devices were preferred by the community (*e.g.,* Sartorius Airport MD8 and DustTrack). Training non-technical community organizers to deploy them was easier; they are less prone to error and need less troubleshooting. Extra gadgets (*e.g.,* the $99 Apple pencil for the iPads) were never used in the field and would not be purchased again.

Deploying a well-trained recruitment team to identify participants

After a final protocol was established, participants were recruited from the top 10 hog producing counties in North Carolina on a rolling basis. On weekly phone calls, JHU and REACH ensured that balanced numbers of IHO-employed and community referent households were recruited.

Due to work on a similar study in the same location in the past,[181] community members were more inclined to participate, given that they were assured that their identities would be kept confidential and that this work was helping the community. One of the community researchers was fluent in Spanish to ensure that Spanish-speaking households could be included in the study. This person was a former IHO worker, which anecdotally, gave IHO-working participants an increased sense of comfort.

Retaliatory job loss was a major concern of all parties in this pilot project and maintaining participant confidentiality was of the utmost importance. For this reason, questions about foreign worker documentation or birth place were not asked.

Field data collection by trained community organizers

Data were collected from November 2017 through April 2018, with two to three homes sampled per week, the maximum capacity laboratory staff could handle. Teams of two community organizers were deployed to each home at a pre-scheduled time when the adult (either an IHO worker or a person not employed at any CAFO facility) and a child under the age of seven who lived in the house were present. The first community organizer remained in the home, and the second moved outside once consent/assent forms were signed.

Data collection inside the home consisted of: (1) separate adult and child surveys; (2) flocked environmental swabs (Copan Diagnostics Inc., Murrieta, California); (3) house dust via vacuum collection of a common room floor; (4) flocked nasal swabs (Copan Diagnostics Inc., Murrieta, California); and oral fluid sponge-like swabs. Both the environmental swabs and floor dust collection were conducted to assess the home environment for *Staphylococcus aureus* and a swine-specific fecal microbial source tracking marker *(i.e.*, Pig-2-bac), as were the nasal swabs. Up to six indoor surfaces were to be swabbed using prior studies as a guide to best locations.[182] The oral fluid swabs were used to examine the prevalence of antibodies to microbial exposures.

Mobile device survey data collection

A data collection tool in the form of tablet devices (*i.e.,* iPads) with REDCap survey software was deployed. The REDCap software is intended to display only relevant questions (*e.g.,* If "yes," then please describe), force a participant to respond with at least a "refused to answer" reply before proceeding, and to accept only logical data (*e.g.,* a date of birth could not be more than 120 years ago).

One of the community researchers was fluent in Spanish to ensure that Spanish-speaking households could be included in the study. This person was also a former IHO worker.

After both surveys were collected, the indoor community organizer collected all human swabs, with the parent first to demonstrate the process to the child. They then used environmental swabs to collect dust in six locations in the home, including a field blank. Locations were chosen where settled dust was likely to collect and where there would be human interaction with the surfaces. Ideal places included the refrigerator and refrigerator handle, the TV and TV remote, an air-conditioning unit, and window sill. Organizers were instructed to use these as a guide, allowing flexibility to collect swabs in alternative locations as needed. Finally, they vacuumed to collect floor dust.[180]

Data collection outside the home

Data collection outside the home consisted of: (1) a weather monitor (Kestral 5500 Weather Meter, Kestral Instruments, Boothwyn, PA); (2) a high-volume air sampler (Airport MD8, Sartorius, Goettingen, Germany); (3) a particulate matter (PM) monitor (DustTrak DRX Aerosol Monitor 8533, TSI**,** Shoreview, Minnesota); and (4) flocked environmental swabs (Copan Diagnostics Inc., Murrieta, California). Upon leaving the house, the outdoor community organizer set up the weather monitor away from any obstructions in the yard and out of sight of nosy neighbors.

The AirPort MD8 was then assembled and run for 20 min (1000L). To keep a low profile it was determined that the Airport would be placed atop the organizer's car. During this time, the organizers collected Copan swabs from three locations and a field blank. It was determined that ideal locations to recover Pig-2-bac (a bacterial marker of pig fecal matter) and *S. aureus* would be those out of direct sunlight, in the direction of the IHO, and where rainfall would not likely wash away the bacteria. Organizers were therefore instructed to swab under air conditioning units, under window sills, and along the underside of siding planks if possible. Disposable cardboard cutouts to aid in measuring a 12 in^2 area to be swabbed were used.

To assess distance decay in airborne PM from IHOs to participant homes the organizer then walked pre-determined transects across the property, away from the IHO using the particulate monitor.

To track each movement in space a handheld Garmin GPS unit was used, marking waypoints at each outdoor sampling site, and a paper record sheet to link the waypoint number and activity. Large preprinted labels (Avery 5160) were used to note organizer, time, date, and sample type and number. These were affixed to samples as well as log sheets. Anecdotally, the organizers noticed that the preprinted labels were used to aided in organization and efficiency.

Data collection outside the home could have benefitted from another community organizer to assist in labelling and record keeping. The GPS unit chosen had a nob that was relatively difficult for the organizers to use. The original plan envisioned the collection of hydrogen sulfide and ammonia measurements, but the available tools were either cost-prohibitive (Jerome J605) or did not read low enough concentrations for these purposes. During training sessions REACH staff initially had the weather monitor mounted on a tripod but found that temporary plastic fence-post stakes (*e.g.*, Powerfields Poly Step In Post) worked better and were less expensive.

Data collection of companion animals

Community members were concerned about their own health effects from living in proximity to IHOs, and when asked about the health of their pets, they additionally expressed concern that their pets also might suffer health effects from IHO exposures. Therefore, survey data and companion animal sample collection were performed on a subset of pet-owning homes during the pilot study. Six dogs from three households were enrolled and sampled by trained veterinarians from JHU using swabs and an established protocol.[183] The research team, based on professional experience, advised that it was inadvisable for community organizers, who had widely varying experience with animals, to conduct this work due to personal risk of injury from pet bites or scratches.

Data completeness and quality reviews and assessments

All REDCap data were transferred to Stata (StataCorp, LP. 2017. Stata Statistical Software: Release 15. College Station, TX) for analysis. The total number of records for all participants was used as the denominator for data completeness calculations.

While 50 households from both IHO-worker families and non-IHO worker families were intended to be enrolled, 18 eligible IHO worker household and 20 eligible community referent households were ultimately enrolled (**Table 3.1**) due to time and budget constraints. Eleven households were deemed ineligible after data review (*i.e.,* had a child enrolled who was seven years old, instead of under seven per protocol). Community organizers were encouraged to recruit as many people in the household as possible, but only one household with more than the minimum one adult and one child was enrolled. This was in part due to the length of the surveys. They were very long with ~400 questions per adult and ~100 per child depending on branching logic. Additionally, the incentive structure was based on household enrollment, not per person enrollment.

In **Table 3.1** the number of household swab and environmental samples collected is detailed. Of human swab samples collected none were missing. However, some environmental swabs (up to 9% for a given participant category) were reported missing by the laboratory.

Table 3.2 details the number of survey questions collected and the percentage missing. Overall, REDCap data was missing in 2.4% of 18,932 total records. Using chi-square analyses, missingness did not differ by eligibility or IHO worker home *vs.* community referent (**Table 3.2**). Missing data were most common for those questions inquiring if participants had any questions (n=65), to identify body parts affected (n=42), and to specify a prior answer (n=40). Missing data was less common after weekly data checks began in the tenth week (11 questions on average *vs.* 4 respectively) (**Figure 3.3**).

Data were less complete for surveys in REDCap compared to data completeness for surface and nasal swabs and dust samples. This may have been due to extensive trainings that were completed with REACH for swab sample collection compared to survey administration. REACH also checked and logged swab sample inventories before shipments to JHU and UNC for sample processing. REDCap data were checked by JHU researchers and then identified concerns had to be relayed back to REACH to clarify responses. The participants were not re-contacted if they had missing data (*e.g*., or refusal of response).

In examining the missingness of data from this study in 2018 and a previous study in 2014 (see Chapters 1 and 2) using identical questions, but the earlier on paper, and this electronic, we see an improvement in data completeness (**Table 3.4**). While the missingness in the prior study is relatively minimal for most variables and both are small in size, it is an indication that the use of the electronic system was implemented successfully to gather more complete records. A large improvement in missingness was seen in the questions regarding current smoking status (24% to 0%).

The digital REDCap system eliminated both the time-consuming hand-entry of data and multiple rounds of data checking for entry errors (e.g., time required to complete data entry of paper-based responses into Excel and to check for data entry errors), but still necessitated long hours of data review each week. In an ideal situation, data would have been reviewed by the academic partners weekly, in order to check data completeness and quality and then any queries and/or clarifications would have been delivered back to the community partners. However, on weeks when this did not happen, more data were missing.

Drawbacks to the use of REDCap stemmed from a lack of prior use. This was noted in the ineligibility of 11 households due to the enrollment of a child age seven, and not *under* the age of seven (**Table 3.5**). Had the fields been set up correctly this error should have stopped the survey after an organizer entered age seven into the child's age field, and reducing the number of invalid responses.

The REDCap system was new to the community partners and relatively new for the academic partners. Prior collaborative work had used paper copies of surveys. There is a steep learning curve and the manner in which some surveys were constructed was not efficient. Further, delays in data review by JHU stemmed from a lack of familiarity with the program, leading to 10 household being identified as ineligible based on a child seven years of age being enrolled, instead of *under* the age of seven. It would be recommended that researchers new to REDCap work closely with a REDCap consultant to create surveys that can be reviewed and analyzed easily at weekly intervals. Also, community organizers carried handouts with photos of *S. aureus* infections and different mask types as well as backup copies of paper questionnaires in case an iPad or the REDCap application failed. The photos were also uploaded and accessible within the REDCap system, but researchers reported difficulty accessing electronic versions of these files while they were administering the survey.

While academic partners provided scientific guidance and training, this research would not have been possible without community-driven research. REACH was key to enrolling participants and maintaining a relationship with a hard-to-reach population of IHO workers. In subsequent work it would be advisable to check the eligibility of each participant prior to starting data collection and to check data at the end of each week for completeness and quality.

CONCLUSIONS

Using the tenets of community-driven research (CDR), academic and community partners expanded upon a long-standing collaboration to answer lingering questions about swine-specific microbial contamination of household surfaces and human nasal swabs at residences proximal to IHOs. CDR is an effective approach to investigate high-priority questions of IHO workers and community residents without endangering participants' job security or privacy. Because this approach was participatory – involving trainings of citizen scientists – it also built capacity of community members' that may lead to improvements in future larger studies. The REACH team now not only physically has access to new equipment, but also has the knowledge base to deploy their own study staff to conduct work they are interested in pursuing, like a rapid response team. This pilot demonstrated how trained community members could collect complete and high-quality data about community exposures to airborne IHO contaminants in an efficient and accurate manner. Microbial source tracking measurements represent a powerful tool that was shown to be implementable in a CDR setting. In the future this work should be expanded and implemented in other communities who want to determine whether microbial exposure burdens from IHOs are reaching their homes and nares.

TABLES

Table 3.1. Number of physical samples collected and missing among all eligible households compared to those that were ineligible in a community-driven research (CDR) pilot project, North Carolina 2017-2018.

	Eligible households		**Ineligible households**	
	Industrial hog operation	Community referent	Industrial hog operation	Community referent
Total, n	18	20	8	3
High volume outdoor air, n	18	20	8	3
Missing, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Environmental swabs*				
Outdoor, n	105	115	47	17
Missing, n (%)	3 (3)	5 (4)	3 (6)	1 (6)
Indoor, n	102	109	48	18
Missing, n (%)	5 (5)	11 (9)	1 (2)	0 (0)
Human swabs				
Nasal, n	36	41	16	6
Missing, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Microbiome, n	36	41	16	6
Missing, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Viral, n	36	41	16	6
Missing, n (%)	0 (0)	0 (0)	0 (0)	0 (0)

*At three ineligible IHO worker households seven environmental swabs were collected (either indoor or outdoor, but not both from the same household), when six were instructed to be collected.

Table 3.2. Data completeness and quality for REDCap survey questions in a community-driven research (CDR) pilot project, North Carolina 2017-2018.

	Eligible industrial hog operation households		**Eligible community referent households**	
	Workers	Children	Workers	Children
Total required questions, n	4698	2916	3680	3381
Missing, n (%)	112 (2)	71 (2)	125 (3)	45 (1)
Invalid, n (%)*	2 (0)	0 (0)	13 (0)	0 (0)
	Ineligible industrial hog operation households		**Ineligible community referent households**	
	Workers	Children	Workers	Children
Total required question, n	1827	1134	552	483
Missing, n (%)	68 (4)	37 (3)	30 (5)	12 (3)
Invalid, n (%)*	2 (0)	1 (0)	2 (0)	0 (0)

Note. "Invalid" is defined as errors in response values outside of pre-specified ranges or type mismatch from what was programmed in as acceptable in REDCap surveys.
*Percentage calculated using the number of invalid responses over the total required questions minus the missing questions.

Table 3.3. Demographics of eligible compared to ineligible participants in a community-driven research (CDR) pilot project, North Carolina, 2017-2018.

	Eligible industrial hog operation households		**Eligible community referent households**	
	Workers	Children	Workers	Children
n	18	18	20	21
Age in years, mean (SD)	41 (12)	3 (2)	34 (10)	4 (2)
Years worked on any IHO, mean (SD)	10 (8)	-	-	-
Sex, n (%)				
Male	6 (33)	11 (61)	1 (5)	15 (71)
Female	12 (67)	7 (39)	19 (95)	6 (29)
Race/ethnicity, n (%)				
Hispanic, non-black	10 (56)	9 (50)	10 (50)	10 (48)
Black	6 (33)	6 (33)	10 (50)	11 (52)
Other	2 (11)	3 (17)	0 (0)	0 (0)
Current cigarette smoker, n (%)				
Yes	3 (100)	-	20 (100)	-
No	-	-	0 (0)	-
Health insurance, n (%)				
Yes	12 (67)	18 (100)	14 (70)	21 (100)
No	6 (33)	0 (0)	6 (30)	0 (0)
	Ineligible industrial hog operation households		**Ineligible community referent households**	
	Workers	Children	Workers	Children
n	8	7*	3	3
Age in years, mean (SD)	42 (10)	7 (0)	43 (14)	7 (0)
Years worked on any IHO, mean (SD)	9 (5)	-	-	-
Sex, n (%)				
Male	4 (67)	4 (67)	2 (67)	2 (67)
Female	2 (33)	2 (33)	1 (33)	1 (33)
Race/ethnicity, n (%)				
Hispanic, non-black	3 (43)	4 (57)	1 (33)	1 (33)
Black	1 (14)	1 (14)	2 (67)	2 (67)
Other	3 (43)	2 (29)	0 (0)	0 (0)
Current cigarette smoker, n (%)				
Yes	1 (100)	-	1 (33)	-
No	-	-	2 (67)	-
Health insurance, n (%)				
Yes	6 (86)	6 (86)	3 (100)	3 (100)
No	1 (14)	1 (14)	0 (0)	0 (0)

*The questionnaire wasn't completed for one of the 8 ineligible IHO worker children, but a nasal swab sample was collected.

Table 3.4. Demographics of eligible industrial hog operation (IHO) worker participants in two studies, North Carolina, 2017-2018.

	Aims 1 and 2 (paper survey)		Aim 3 (REDCap survey)	
Characteristic	**Reports, n**	**Mean (SD)**	**Reports, n**	**Mean (SD)**
Workers in cohort	103	-	18	-
Age in years	97	38 (11)	17	41 (12)
Missing	6	-	1	-
Characteristic	**Reports, n**	**%**	**Reports, n**	**%**
Sex				
Male	55	53	6	33
Female	46	45	12	67
Missing	2	2	0	0
Race/ethnicity				
Hispanic, non-black	88	85	10	33
Black	12	12	6	56
Other	0	0	2	11
Missing	3	3	0	0
Education status				
Less than high school education	47	46	4	22
High school degree/GED or higher or other	52	50	14	78
Missing	4	4	0	0
Current cigarette smoker				
Yes	13	13	3	17
No	65	63	15	83
Missing	25	24	0	0
Health insurance				
Yes	48	47	12	67
No	52	50	6	33
Missing	3	3	0	0
Lived on same property as an IHO				
Yes	8	8	0	0
No	89	86	18	100
Missing	6	6	0	0

Table 3.5. Data quality of the age variable, a determining factor for eligibility in a community-driven research (CDR) project, North Carolina, 2017-2018.

	Eligible industrial hog operation households		**Eligible community referent households**	
	Workers	Children	Workers	Children
Number recruited	18	18	20	21
Age, n	17	18	20	21
Missing, n (%)	1 (6)	0 (0)	0 (0)	0 (0)
Incorrect data type, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Out of range, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Outliers, n (%)	0 (0)	0 (0)	0 (0)	1 (6)
	Ineligible industrial hog operation households		**Ineligible community referent households**	
	Workers	Children	Workers	Children
Number recruited	8	7	3	3
Age, n	5	6	3	3
Missing, n (%)	3 (38)	1 (14)	0 (0)	0 (0)
Incorrect data type, n (%)	0 (0)	0 (0)	0 (0)	0 (0)
Out of range,* n (%)	0 (0)	6 (100)	0 (0)	3 (100)
Outliers, n (%)	0 (0)	0 (0)	0 (0)	0 (0)

*Out of range defined as the child's age being 7 years or older for the child that determined the household's eligibility.

FIGURES

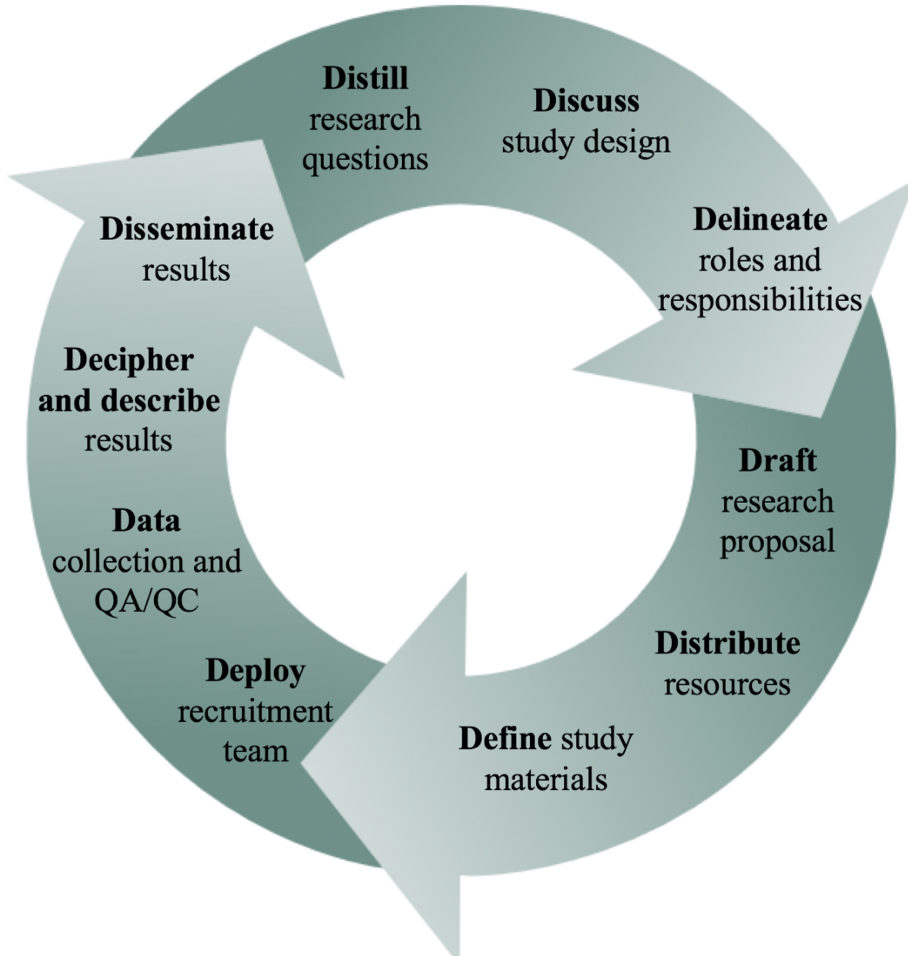

Figure 3.1. Iterative process* used in a community-driven research (CDR) pilot project, North Carolina 2017-2018.

*Process started with the distillation of research questions.

Prior work in *this* community	**Current pilot**
Kestrel weather monitor	Kestrel weather monitor
SKC-brand button samplers set in a half-circle facing an IHO near property line run for 8hrs	One Sartorius-brand high-volume sampler set atop a car and run once for 20min
Paper surveys	REDCap software on an iPad not equipped with Wi-Fi
Nasal and cheek swabs	Nasal and cheek swabs
Digital logtagger	Analog refrigerator thermometer

Prior work in *other* communities	**Current pilot**
A veterinarian swabbed pets using a Swiffer and Copan swabs in pre-determined sites	A veterinarian swabbed pets using a Swiffer and Copan swabs in pre-determined sites
Vacuuming inside floors without moving furniture and in between bedsheets	Vacuuming inside floors without moving furniture and not in the bedroom
Indoor and outdoor Copan swabs	Indoor and outdoor Copan swabs
Large, stationary air monitor in a trailer	DustTrack portable PM monitor

Figure 3.2. Sampling equipment decisions and rationale in prior and current community-driven research (CDR).

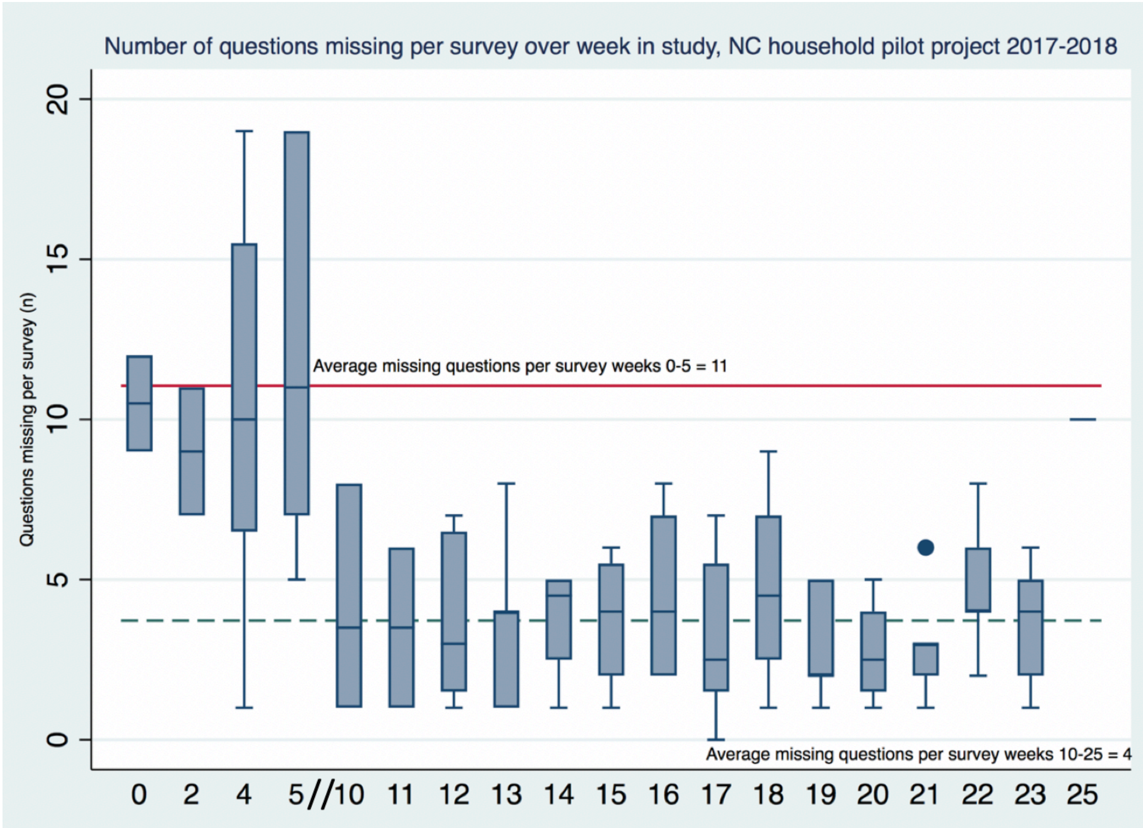

Figure 3.3. Box and whisker plots of missing required REDCap questions each week in study during a community-driven research (CDR) pilot project, North Carolina 2017-2018.

MISCELLANEOUS RESULTS

Summary of Findings

Chapter 1

The first three tables presented in this section (**Tables M1.1-3**) describe the longitudinal worker cohort in greater detail than in the truncated published versions. They show the percent missingness for key variables that were explored, and some that were not presented in the previous chapters. Missingness was relatively small for most baseline participant variables except current smoking status (24%) and body mass index (BMI) (7%) (**Table M1.1**). Missingness was also relatively small for baseline on-IHO work activities, except for reports of ever handling pig manure (12%) and which life stages participants typically worked with (8%) (**Table M1.2**). Missingness of baseline health outcomes was also small (0-4%), as shown in **Table M1.3**. We have also shown the prevalence of COPD within the cohort (4%), with two of these participants who reported COPD also reporting asthma (cross-tabulation not shown).

To assess the possibility of imputing exposures or outcomes for those missing responses, associations between missing data and key exposures and outcomes were then examined (**Tables M1.4-11**). For analyses in **Tables M1.4-8** those persons with missing variables were coded as 1, and those with data were coded as 0. Simple logistic regression models were run with missingness as the outcome and *p*-values for the associations reported. In analyses for **Tables M1.9-10** an indicator variable was created for missingness in exposure and outcome categories, where the referent group was records that had no missing category components. For **Table M1.11** a chi-square test to assess the association between the different interviewers and missing data was used.

Overall, there were enough associations between missingness and exposures, outcomes, and interviewers to show that missingness was not at random and that imputation was not a statistically reasonable method to handle these missing data.

Figure M1.1 offers an alternative view of loss-to-follow-up in the IHO worker cohort from that published in Chapter 1. Only three participants of (103) had no records for longitudinal analyses.

Expanded longitudinal data are then presented in **Tables M1.12-13**, with missingness for each variable described. Again, missingness is minimal in these data, particularly with health outcomes (0-4%) (**Table M1.12**), the most being present in reports of temperature (7%), vent fans being off (6%), and malodor (6%) (**Table M1.13**).

In published analyses, stratification of exposure and outcomes categories by reports of consistent mask usage (defined as the average reported percentage of mask usage over the longitudinal visits of at least 80%) and inconsistent mask usage (less than 80%) were presented. Here, the unaggregated exposure components and binary outcomes measures stratified by consistent mask usage are shown (**Tables M1.14-15b**). While some associations are statistically significant at the $\alpha<0.05$ level (bolded), correction for multiple comparisons was not conducted, and no conclusive patterns were shown.

Chapter 2

Tables found in this section display comparisons between Piko-1 and Koko spirometry device measurements and sensitivity analyses of work presented in published work. Here tables presented in Chapter 2 are expanded upon and display missingness (**Table M2.1**).

In Chapter 2 analyses assessment for whether published values for Piko-1 compared to reference instruments were similar to the Koko brand machine, as in comparison studies other gold standard spirometers, not the Koko, were employed. To determine the differences and decide whether a correction factor could be applied to Piko-1 measurements Bland-Altman plots were used (**Table M2.2 and Figure M2.1-5**). There were no clear patterns in the differences in paired maneuvers; therefore no correction for differences between the reference and Piko-1 instruments was made.

In a field trial of Piko-1 devices, Rothe *et al*. (2012) found that Piko-1 measurements were ~3% lower than corresponding pneumotach measurements, although they did not use the Koko as a reference instrument.[184] They also found no evidence of heterogeneity between Piko-1 devices. Dal Negro *et al*. (2016) found similar discrepancies, with Piko-1 overestimating FEV_1 values by 4% and underestimating PEFr values by 8%.[185] This falls in line with the published accuracy of the Piko-1 device by the manufacturer: 3.5% for FEV_1.[186] In data not shown 68 paired Koko and Piko-1 FEV_1 measurements were compared. Mean differences of 0.17L and PEFr measurements of -0.73L/s, an overestimation of FEV_1, and an underestimation of PEFr by Koko, results similar to the previously published differences, were observed.

Assessment for the reasons for maneuvers to be classified as unacceptable according to NIOSH standards (*i.e.,* not having three tries or having non-reproducible tests) is then shown. The most likely reason for a spirometry measure in the data set to not meet NIOSH acceptability criteria would be due to a lack of reproducibility, not due to the lack of maneuvers attempted (**Table M2.3**). It is important to note that while these tests may not meet the critieria for valid tests results, ATS has determined that there may still be valuable information within them and that clincians should not disregard them entriely if the manuevers did not suffer from an extra breath, cough, or other such egregious problems.[187]

Therefore, a long series of sensitivity analyses to assess the changes to point estimates when resticting our analyses to only those tests that conformed to NIOSH standards at baseline was performed at baseline (**Table M2.5a-7b** and **9a-11b**) and over time (**Table M2.13-14, 16-18, 21-22,** and **M2.24-25**). Sensitivity analyses of the chosen published models using all best spirometry measures, regardless of reproducibility or number of maneuvers, are also shown **(Table M2.8a-8b, 12a-12b, 15, 19-20,** and **23).**

This chapter is closed with generalized estimating equation (GEE) models (**Table M2.26-29)**. These were not used in main analyses, as the research questions revolved around personal changes to exposure and they do not adequately control for confounders (see **Detailed Methods**). However, this is the method past researchers have employed, and these show the similarities between overall interpretations with fixed-effects regression analyses.

Chapter 3

In Chapter 3 two tables are is presented. **Table M3.1** shows the particpant of industrial hog operation (IHO) workers in a community-driven research (CDR) pilot project, North Carolina 2017-2018 compared those industrial hog operation (IHO) workers in a prior cohort, North Carolina 2013-2014 in a longer format than seen in Chapter 3 and also describes missingess.

Table M3.2 shows the use of masks on-IHO of workers. In the pilot study from which the data for Chapter 3 is derived, community and academic partners wanted to better understand what face masks were being worn and whether employers were providing the masks or training about their use. Very little research has been conducted to assess what PPE is being used on IHOs. In 2013, Donham *et al*. examined changes in PPE use after an intervention study in Iowa.[188] However, this was only owner-operators. In 2015, Kearney *et al*. conducted a cross-sectional telephone interview of farmers in eastern N.C. but failed to reach our day-to-day IHO workers, instead mostly contacting white, male owners of grain, soybean, and cotton farms.[189] Further, both partners had lingering questions regarding the airborne movement of waste off-IHO, which were bolstered by public political debates regarding the lawsuits at the time and legislation proposed to stop them.

These workers are not the same as those who are presented in Chapters 1 and 2 but from a secondary data collection undertaking conducted three years later. While not the primary goal of this data collection, it did allow for the addition of questions for which gaps in knowledge remained, including details regarding the type of masks used, if they were provided by employers, and if employers provided training. The use of an N95 respirator has been shown to significantly reduce endotoxin exposure and bronchial responsiveness compared to those who did not don the respiratory protection before exposure to pig barn dust for three hours.[170] Although a small sample size (N=19), consistency was seen in the responses indicating that of those surveyed all were wearing masks at least sometimes (47%), most were wearing N95 respirators (89%), most indicated that their employer provided a mask (89%), and that most had received training on their use (79%) (**Table M3.1**).

Tables and Figures of Findings

Chapter 1

Table M1.1. Baseline demographics and household characteristics within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, including missingness for each variable.

Characteristic	**Reports, n**	**Mean (SD)**
Workers in cohort	103	-
Age in years	97	38 (11)
Missing	6	-
Height in centimeters	96	165 (11)
Missing	7	-
Weight in pounds	96	172 (32)
Missing	7	-
Characteristic	**Reports, n**	**%**
Sex		
Male	55	53
Female	46	45
Missing	2	2
Race/ethnicity		
Hispanic, non-black	88	85
Black	12	12
Missing	3	3
Education status		
Less than high school education	47	46
High school degree/GED or higher	52	50
Missing	4	4
Body mass index (BMI)		
<30.0	58	56
≥30.0	38	37
Missing	7	7
Used a gym or workout facility in the last three months		
Yes	9	9
No	92	90
Missing	2	2

Current cigarette smoker		
Yes	13	13
No	65	63
Missing	25	24
Health insurance		
Yes	48	47
No	52	50
Missing	3	3
Place where IHO workers seek medical care[a]		
Private doctor	49	48
Emergency department or urgent care center	29	28
Hospital	18	17
Free clinic	16	16
Other	3	3
Does not seek medical care under any circumstance	4	4
Missing	4	4
Hobbies outside of work (auto repair or use of chemicals)		
Yes	6	6
No	92	89
Missing	5	5
Had a cat or dog		
Yes	44	43
No	50	48
Missing	9	9
Lived on same property as an IHO		
Yes	8	8
No	89	86
Missing	6	6
Season of visit		
Winter	51	50
Fall	52	50
Missing	0	0
Month of baseline visit		
January	1	1
February	50	49
October	30	29
November	22	21
Missing	0	0

[a]Categories are not mutually exclusive.

Table M1.2. Baseline work activities within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, including missingness.

Characteristic	Reports, n	Mean (SD)
Years worked on any IHO	87	8 (6)
Days worked per week	97	6.4 (0.8)
Days since last IHO work shift	78	0.38 (0.8)
Percent of time at work spent in direct contact with hogs	94	82 (27)
Characteristic	**Reports, n**	**%**
Ever handled dead pigs		
Yes	77	75
No	21	20
Missing	5	5
Ever came into direct contact with or touched pig manure		
Yes	61	59
No	30	29
Missing	12	12
Ever give pigs shots or injections		
Yes	68	66
No	30	29
Missing	5	5
Ever give antibiotics to pigs		
Yes	60	58
No	37	36
Missing	6	6
Ever draw blood or collect other fluids from pigs		
Yes	9	9
No	89	86
Missing	5	5
Worked with[a]		
Breeding pigs (sow, farrow, or wean)		
Yes	52	50
No	45	44
Missing	6	6
Nursery pigs		
Yes	21	20
No	74	72
Missing	8	8
Finisher hogs		
Yes	21	20
No	74	72
Missing	8	8

Feeder pigs		
Yes	13	13
No	81	77
Missing	8	8
Ever apply pesticides (this could include chemicals used to kill insects, rodents, or other pests) inside or around the barns where pigs are kept		
Yes	48	47
No	50	49
Missing	5	5
Wore coveralls/full body suit		
Always	68	66
Sometimes	14	14
Never	15	16
Missing	6	6
Wore a mask		
Always	37	36
Sometimes	43	42
Never	18	17
Missing	5	5
Wore glasses/goggles		
Always	22	21
Sometimes	34	33
Never	42	41
Missing	5	5
Clothes worn at work at the hog operation ever washed with the laundry of your household members		
Yes	16	16
No	80	78
Missing	7	7
Direct contact with pigs[b]		
Yes	94	91
No	4	4
Missing	5	5
Showered after work		
Always	93	90
Sometimes	2	2
Never	3	3
Missing	5	5
Took any personal protective equipment (PPE) home		
Yes	4	4
No	94	91
Missing	5	5

[a]Categories are not mutually exclusive.
[b]Direct contact with a pig or hog means touching the animal with any part of your body including your hands, feet, arms or legs, even if you were wearing clothing or protective gear.

Table M1.3. Baseline self-report of health issues within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, including missingness.

	Reports, n (%)
Ever had eye irritation	
No	80 (78)
Yes	19 (18)
Missing	4 (4)
Within the last month	
No	6 (32)
Yes	12 (63)
Missing	1 (5)
Ever had nose irritation	
No	84 (82)
Yes	16 (16)
Missing	3 (3)
Within the last month	
No	5 (31)
Yes	10 (63)
Missing	1 (6)
Ever had throat irritation	
No	85 (83)
Yes	15 (15)
Missing	3 (3)
Within the last month	
No	2 (13)
Yes	13 (87)
Missing	0 (0)
Any allergies	
No	86 (84)
Yes	13 (13)
Missing	4 (4)
Doctor-diagnosed asthma	
No	94 (91)
Yes	9 (9)
Missing	0 (0)
Chronic obstructive pulmonary disease (COPD)/Emphysema	
No	95 (92)
Yes	4 (4)
Missing	4 (4)

Table M1.4. Baseline binary missingness of eye, nose, or throat symptoms within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, all are binary unless otherwise noted.

	Missing reports of eye, nose, or throat symptoms (n=5 of 103)	
	n	*p*-value
Age (continuous)	97	0.086
Weight in pounds (continuous)	96	0.138
Current cigarette smoker	78	0.248
Height (cm)	96	0.318
Sex	101	0.470
Hispanic race/ethnicity	-	-
Education status	-	-
Used a gym or workout facility in the last three months	-	-
Health insurance	-	-
Lived on same property as an IHO	-	-
Have you ever		
Given pigs shots and/or antibiotics	-	-
Drawn pigs blood	-	-
Handled pig manure	-	-
Applied pesticides in or around the barns	-	-
Washed work clothes with household laundry	-	-
Do you typically		
Work exclusively in sow, nursery, and/or farrow barns	-	-
Work exclusively in feeder and/or finisher barns	-	-
Always wear a mask and coveralls/ full bodysuit and eye protection	-	-
Years worked on an IHO (tertile)	87	0.318
Percent of life working on an IHO (tertile)	84	0.387
Worked seven days per week	-	-
Percent of time at work spent in direct contact with hogs (tertile)	-	-

- = model did not converge.

Table M1.5. Baseline binary missingness of any allergies within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, all are binary unless otherwise noted.

	Missing reports of any allergies (n=4 of 103)	
	n	*p*-value
Age (continuous)	97	0.931
Weight in pounds (continuous)	-	-
Current cigarette smoker	-	-
Height (cm)	96	0.219
Sex	-	-
Hispanic race/ethnicity	-	-
Education status	-	-
Used a gym or workout facility in the last three months	-	-
Health insurance	100	0.954
Lived on same property as an IHO	-	-
Have you ever		
Given pigs shots and/or antibiotics	-	-
Drawn pigs blood	-	-
Handled pig manure	-	-
Applied pesticides in or around the barns	-	-
Washed work clothes with household laundry	-	-
Do you typically		
Work exclusively in sow, nursery, and/or farrow barns	-	-
Work exclusively in feeder and/or finisher barns	-	-
Always wear a mask and coveralls/ full bodysuit and eye protection	-	-
Years worked on an IHO (tertile)	87	0.803
Percent of life working on an IHO (tertile)	-	-
Worked seven days per week	-	-
Percent of time at work spent in direct contact with hogs (tertile)	-	-

- = model did not converge.

Table M1.6. Longitudinal binary missingness of at least one respiratory symptom within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**At least one respiratory symptom* (missing=22 of 782)**	
	obs. (workers)	*p*-value
Number of sick pigs	743 (100)	0.488
Number of dead pigs	-	-
Percentage of the time a mask was worn	737 (101)	0.208
Any hot or dusty barn conditions[a]	-	-
Conducted any pesticide application or cleaning activity[b]	-	-
Administered pigs medicine or shots[c]	739 (100)	0.852
Two or three of the above[d]	-	-
Used any PPE[e,f]	-	-
Handwashing at least 8 times per shift[g]	737 (100)	0.954

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

- = model did not converge.
* = Excessive coughing, runny nose, difficulty breathing, or sore throat.

Table M1.7. Longitudinal binary missingness of any symptom that interfered with sleep within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**At least one symptom interfered with sleep*** **(missing=37 of 782)**	
	obs. (workers)	*p*-value
Number of sick pigs	743 (100)	0.283
Number of dead pigs	745 (100)	0.468
Percentage of the time a mask was worn	737 (101)	0.523
Any hot or dusty barn conditions[a]	718 (99)	**0.013**
Conducted any pesticide application or cleaning activity[b]	742 (99)	**0.042**
Administered pigs medicine or shots[c]	739 (100)	0.448
Two or three of the above[d]	705 (99)	0.052
Used any PPE[e,f]	729 (100)	0.172
Handwashing at least 8 times per shift[g]	737 (100)	0.487

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

- = model did not converge.
* = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

Table M1.8. Longitudinal binary missingness of reports of headache, sneezing, or eye and/or nose symptoms within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**Headache, sneezing, or eye and/or nose symptoms (missing=19 of 782)**	
	obs. (workers)	*p*-value
Number of sick pigs	743 (100)	0.488
Number of dead pigs	745 (100)	0.620
Percentage of the time a mask was worn	737 (101)	0.268
Any hot or dusty barn conditions[a]	-	-
Conducted any pesticide application or cleaning activity[b]	-	-
Administered pigs medicine or shots[c]	739 (100)	0.849
Two or three of the above[d]	-	-
Used any PPE[e,f]	-	-
Handwashing at least 8 times per shift[g]	737 (100)	0.959

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

- = model did not converge.

Table M1.9. Longitudinal levels of missingness of at least one respiratory symptom (dummy variable) within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**At least one respiratory symptom*** **(missing=22 of 782)**		
	obs. (workers)		*p*-value
Number of sick pigs	743 (100)	All present	Ref (1.0)
		All missing	0.741
		Some missing	**0.000**
Number of dead pigs	745 (100)	All present	Ref (1.0)
		All missing	0.855
		Some missing	**0.000**
Percentage of the time a mask was worn	737 (101)	All present	Ref (1.0)
		All missing	0.396
		Some missing	0.850
Any hot or dusty barn conditions[a]	718 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	0.997
Conducted any pesticide application or cleaning activity[b]	740 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	0.643
Administered pigs shots or medicine[c]	739 (100)	All present	Ref (1.0)
		All missing	0.517
		Some missing	-
Two or three of the above categories[d]	705 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	0.867
Used any PPE[e,f]	729 (100)	All present	-
		All missing	-
		Some missing	-
Handwashing at least 8 times per shift[g]	737 (100)	All present	Ref (1.0)
		All missing	0.813
		Some missing	-

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

- = model did not converge.
* = Excessive coughing, runny nose, difficulty breathing, or sore throat.

Table M1.10. Longitudinal missingness of at least one symptom that interfered with sleep (dummy variable) within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**At least one symptom interfered with sleep*** **(missing=37 of 782)** obs. (workers)		*p*-value
Number of sick pigs	743 (100)	All present	Ref (1.0)
		All missing	0.348
		Some missing	0.15
Number of dead pigs	745 (100)	All present	Ref (1.0)
		All missing	0.766
		Some missing	0.432
Percentage of the time a mask was worn	737 (101)	All present	Ref (1.0)
		All missing	0.978
		Some missing	0.646
Any hot or dusty barn conditions[a]	718 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	**0.039**
Conducted any pesticide application or cleaning activity[b]	740 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	**0.017**
Administered pigs shots or medicine[c]	739 (100)	All present	Ref (1.0)
		All missing	0.572
		Some missing	0.739
Two or three of the above categories[d]	705 (99)	All present	Ref (1.0)
		All missing	-
		Some missing	0.058
Used any PPE[e,f]	729 (100)	All present	Ref (1.0)
		All missing	-
		Some missing	0.789
Handwashing at least 8 times per shift[g]	737 (100)	All present	Ref (1.0)
		All missing	0.739
		Some missing	0.189

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

- = model did not converge.
* = Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

Table M1.11. Missingness by interviewer (dummy variable) using cross tabulations within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

	Interviewer *p*-value (Pearson X^2)
At least one respiratory symptom	0.627
At least one symptom interfered with sleep	**0.000**
Headache, sneezing, or eye or nose symptom	0.812
Age	0.778
Sex	0.997
Race/ethnicity	0.984
Any hot or dusty barn conditions[a]	**0.004**
Conducted any pesticide application or cleaning activity[b]	**0.013**
Administered pigs medicine or shots[c]	**0.013**
Two or three of the above categories[d]	**0.001**
Used any PPE [e,f]	**0.008**
Washed hands at least 8 times per shift[g]	**0.009**

[a]Sum of vents off (yes=1, no=0), extreme malodor (yes=1, no=0), hot temperature (yes=1, no=0), a new herd entering the barn(s) (yes=1, no=0), and extreme dust (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), pressure washed (yes=1, no=0), used pesticides (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs medicine (yes=1, no=0) and gave pigs shots (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)
[e]Sum of consistently (≥80% of the time at work) wore the following: coveralls/full body suit (yes=1, no=0), mask (yes=1, no=0), and glasses (yes=1, no=0).
[f]PPE = personal protective equipment.
[g]8 is the median number of times workers reported washing their hands per IHO work shift.

Table M1.12. Self-reported work activities an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, including missingness.

	Exposure activities in the past week	n	Mean (SD)
	Number of days worked	781	6 (1)
	Number of hours worked	748	42 (12)
	Number of hours in direct contact	742	38 (14)
	Number of sick pigs	742	61 (166)
	Number of dead pigs	744	42 (120)
	Days vents were off in the past week	139	5 (2)
	Percentage of the time a mask was used	736	54 (46)
	Exposure activities in the past week	**n**	**%**
Barn condition score factors	Vents off		
	Yes	178	23
	No	557	71
	Missing	46	6
	Malodor		
	None to some	564	72
	Extreme	175	22
	Missing	42	6
	Temperature		
	Cold or comfortable	613	78
	Hot	111	14
	Missing	57	7
	Worked with a new herd		
	Yes	47	6
	No	695	89
	Missing	39	5
	Dustiness in barns		
	None, moderate	705	90
	Extreme	32	4
	Missing	45	6
Cleaning and pesticide score factors	Used cleaning chemical at the IHO		
	Yes	414	53
	No	330	42
	Missing	37	5
	Pressure washed the barns		
	Yes	290	37
	No	456	58
	Missing	35	5
	Applied pesticides on the IHO		
	Yes	224	28
	No	523	67
	Missing	34	4

	Used a torch at the IHO		
	Yes	20	3
	No	728	93
	Missing	33	4
Pig contact score factors	Gave pigs medicine		
	Yes	241	31
	No	501	64
	Missing	39	5
	Gave pigs shots		
	Yes	363	46
	No	376	48
	Missing	42	5

Table M1.13. Self-reported symptoms an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, including missingness.

Symptom in the past week	Reports, n (%)
Excessive coughing	
Yes	22 (3)
No	740 (95)
Missing	19 (2)
Runny nose	
Yes	20 (3)
No	742 (95)
Missing	19 (2)
Irritated nose	
Yes	8 (1)
No	754 (97)
Missing	19 (2)
Congestion	
Yes	8 (1)
No	754 (97)
Missing	19 (2)
Sneezing	
Yes	19 (2)
No	743 (95)
Missing	19 (2)
Headache	
Yes	15 (2)
No	747 (96)
Missing	19 (2)
Eye irritation	
Yes	11 (1)
No	751 (96)
Missing	19 (2)
Body aches	
Yes	8 (1)
No	754 (97)
Missing	19 (2)
Fatigue	
Yes	8 (1)
No	754 (97)
Missing	19 (2)
Difficulty breathing	
Yes	12 (2)
No	749 (96)
Missing	20 (3)
Used breathing medication	
Yes	16 (2)

No	741 (95)
Missing	24 (3)
Waking from sleep due to wheezing	
Yes	11 (1)
No	741 (95)
Missing	29 (4)
Symptoms interfered with sleep	
Yes	10 (1)
No	747 (96)
Missing	24 (3)
Waking from sleep due to phlegm	
Yes	9 (1)
No	743 (95)
Missing	29 (4)

Table M1.14. Self-reported symptoms and continuous measures of work activities stratified by overall consistent mask usage (≥80%) in an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014. Results are presented as OR (95% CI).

In the past week	Overall mask usage	Number of days worked	Number of hours worked (per 10)	Direct contact hours (per 10)	Number of sick hogs (per 100)	Number of dead hogs (per 100)	Number of times washed hands
Any respiratory symptom[a]	≥80%	1.03 (0.61, 1.71)	1.53 (0.89, 2.63)	1.10 (0.76, 1.59)	0.85 (0.46, 1.56)	0.70 (0.23, 2.12)	0.95 (0.80, 1.13)
	< 80%	1.17 (0.75, 1.84)	1.43 (0.71, 2.89)	1.40 (0.72, 2.74)	1.09 (0.83, 1.42)	1.35 (0.83, 2.20)	0.90 (0.77, 1.06)
Any symptoms interfered with sleep[b]	≥80%	1.07 (0.65, 1.75)	1.12 (0.70, 1.81)	0.88 (0.61, 1.28)	1.14 (0.91, 1.44)	1.33 (0.83, 2.11)	1.00 (0.92, 1.10)
	< 80%	1.21 (0.54, 2.73)	**4.05 (1.10, 15)**	**33 (1.58, 685)**	1.23 (0.95, 1.60)	41 (0.84, 1978)	1.11 (0.88, 1.40)
Sneezing	≥80%	0.62 (0.31, 1.21)	1.12 (0.67, 1.85)	0.99 (0.68, 1.45)	1.31 (0.90, 1.43)	1.31 (0.81, 2.12)	1.15 (0.96, 1.37)
	< 80%	1.26 (0.58, 2.75)	0.60 (0.17, 2.12)	0.31 (0.06, 1.47)	1.05 (0.12, 8.83)	4.88 (0.61, 39)	0.85 (0.64, 1.12)
Headache	≥80%	1.11 (0.59, 2.08)	1.68 (0.83, 3.41)	1.40 (0.86, 2.28)	1.10 (0.88, 1.36)		**1.22 (1.02, 1.47)**
	< 80%	1.03 (0.58, 1.83)	0.92 (0.19, 4.47)	0.90 (0.19, 4.35)	**14 (1.11, 185)**		0.84 (0.64, 1.11)
Eye or nose symptoms	≥80%	0.36 (0.10, 1.24)	0.88 (0.42, 1.84)	1.03 (0.58, 1.80)		0.20 (0.00, 119)	1.14 (0.95, 1.38)
	< 80%	1.67 (0.59. 4.71)	2.78 (0.56, 14)	4.45 (0.87, 23)		1.68 (0.69, 4.06)	0.84 (0.65, 1.07)

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval.
Grey = at least one cell did not did not converge
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

Table M1.15a. Self-reported symptoms and binary measures of work activities stratified by overall consistent mask usage (≥80%) in an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014. Results are presented as OR (95% CI).

In the past week	Overall mask usage	Used chemicals	Gave pigs shots	Pressure washed	Gave pigs medicine	Extreme dust
Any respiratory symptom[a]	≥80%	1.09 (0.26, 4.53)	2.73 (0.41, 18)	**6.31 (1.17, 34)**	2.63 (0.74, 9.31)	5.28 (0.84, 33)
	< 80%	1.58 (0.56, 4.41)	**4.91 (1.30, 19)**	1.48 (0.53, 4.15)	**3.26 (1.16, 9.16)**	2.96 (0.27, 33)
Any symptoms interfered with sleep[b]	≥80%	3.18 (0.72, 14)	4.73 (0.45, 50)	**7.98 (1.31, 49)**	4.16 (0.93, 19)	
	< 80%	1.10 (0.17, 7.04)	2.22 (0.31, 16)	2.51 (0.52, 12)	9.05 (0.95, 86)	
Sneezing	≥80%			2.27 (0.39, 13)		
	< 80%			4.85 (0.34, 69)		
Headache	≥80%	0.43 (0.07, 2.76)	4.85 (0.45, 53)		5.17 (0.49, 54)	
	< 80%	2.74 (0.35, 21)	2.37 (0.19, 30)		2.41 (0.36, 16)	
Eye or nose symptoms	≥80%	0.80 (0.06, 11)			4.58 (0.27, 78)	
	< 80%	2.64 (0.47, 15)			3.12 (0.68, 14)	

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval.
Grey = at least one cell did not did not converge
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

Table M1.15b. Self-reported symptoms and binary measures of work activities stratified by consistent mask usage (≥80%) in an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014. Results are presented as OR (95% CI).

In the past week	Overall mask usage	Used pesticides	Vent fans off	Extreme malodor	Contact with breading sows	Hot inside barns
Any respiratory symptom[a]	≥80%	1.70 (0.41, 7.12)	3.31 (0.40, 27)	0.93 (0.24, 3.70)		0.45 (0.07, 3.03)
	< 80%	2.32 (0.79, 6.76)	2.84 (0.97, 8.38)	**3.56 (1.35, 9.54)**		4.69 (0.78, 28)
Any symptoms interfered with sleep[b]	≥80%	3.55 (0.72, 18)	1.07 (0.10, 12)	0.57 (0.14, 2.37)		
	< 80%	9.22 (0.94, 90)	**10.78 (1.16, 100)**	2.13 (0.50, 9.16)		
Sneezing	≥80%		1.82 (0.21, 16)	0.26 (0.05, 1.36)		0.28 (0.04, 1.71)
	< 80%		0.20 (0.02, 2.54)	1.58 (0.34, 11)		3.16 (0.17, 58)
Headache	≥80%	**15.74 (1.68, 147)**	10.88 (0.85, 139)	0.87 (0.20, 3.82)		
	< 80%	5.39 (0.42, 70)	3.24 (0.32, 33)	4.52 (0.70, 29)		
Eye or nose symptoms	≥80%			0.87 (0.12, 6.29)	3.87 (0.17, 89)	
	< 80%			2.92 (0.67, 13)	2.45 (0.12, 52)	

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

OR = odds ratio. CI = confidence interval.
Grey = at least one cell did not did not converge
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

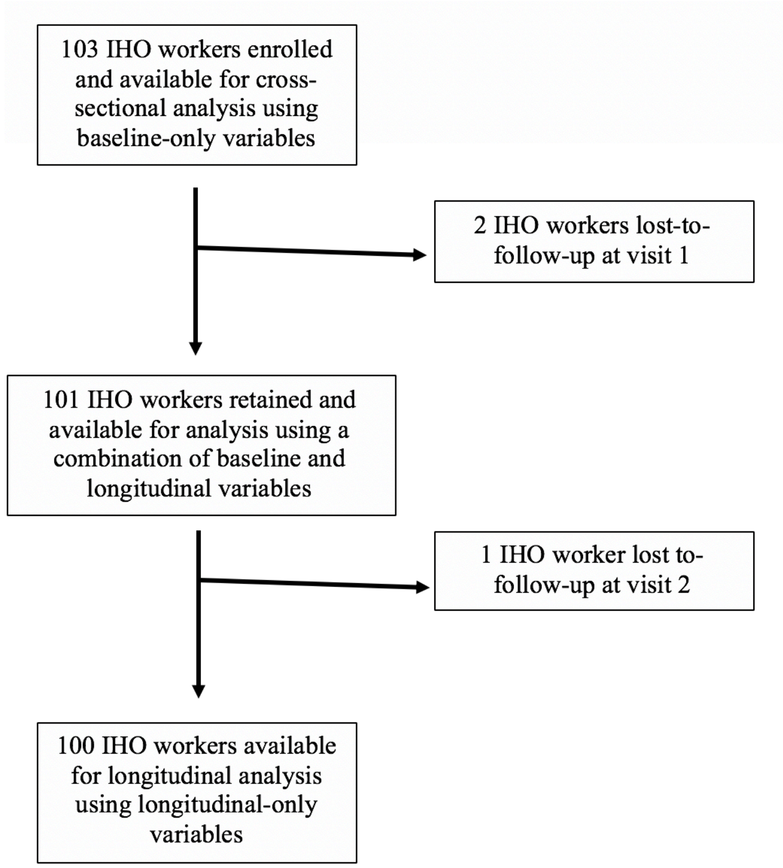

Figure M1.1. Loss-to-follow-up in the IHO worker cohort, North Carolina 2013-2014.

Table M2.1. Baseline spirometry within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

Characteristic	Has Piko-1		Does not have Piko-1		Has Koko		Does not have Koko	
	n	Mean (SD) or %	n	Mean (SD) or %	n	Mean (SD) or %	n	Mean (SD) or %
Workers in cohort	99	-	4	-	69	-	34	-
Age in years, mean (SD)	96	38 (11)	1	25	67	39 (11)	30	35 (9)
Sex, %								
Male	54	55	1	25	34	49	21	62
Female	45	45	1	25	35	51	11	32
Missing	0	0	2	50	0	0	2	6
Race/ethnicity, %								
Hispanic, non-black	88	89	0	0	68	99	20	59
Black	10	10	2	50	0	0	12	35
Missing	1	1	2	50	1	1	2	6
Education status, %								
Less than high school education	47	47	0	0	34	49	13	38
High school degree or GED	41	41	2	50	27	39	16	47
Some college	6	6	0	0	4	6	2	6
College graduate	3	3	0	0	2	3	1	3
Missing	2	2	2	50	2	3	2	6
Height in centimeters, mean (SD)	96	165 (11)	0	-	69	165 (9)	27	166 (14)
Weight in pounds, mean (SD)	96	172 (32)	0	-	69	172 (31)	27	174 (35)
Body mass index (BMI), mean (SD)	96	29 (5)	0	-	69	29 (5)	27	29 (6)
Used a gym or workout facility in the last three months, %								
Yes	8	8	1	25	4	6	5	15
No	91	92	1	25	65	94	27	79
Missing	0	0	2	50	0	0	2	6
Current cigarette smoker, %								

Yes	12	12	1	25	5	7	8	24
No	65	66	0	0	62	90	3	9
Missing	22	22	3	75	2	3	23	68
Health insurance, %								
Yes	46	46	2	50	34	49	14	41
No	52	53	0	0	34	49	18	53
Missing	1	1	2	50	1	1	2	6
Used the following location(s) of medical care if needed, %[a]								
Private doctor								
Yes	49	49	0	0	31	45	18	53
No	48	48	2	50	36	52	14	41
Missing	2	2	2	50	2	3	2	6
Emergency room								
Yes	19	20	0	0	12	17	7	21
No	78	79	2	50	55	80	25	74
Missing	2	2	2	50	2	3	2	6
Hospital								
Yes	16	16	2	50	11	16	7	21
No	80	81	0	0	55	80	25	74
Missing	3	3	2	50	3	4	2	6
Free clinic								
Yes	16	16	0	0	9	13	7	21
No	81	82	2	50	58	84	25	74
Missing	2	2	2	50	2	3	2	6
Urgent care facility								
Yes	13	13	0	0	10	14	3	9
No	84	85	2	50	57	83	29	85
Missing	2	2	2	50	2	3	2	6
Company doctor								
Yes	1	1	0	0	0	0	1	3
No	96	97	2	50	67	97	31	91
Missing	2	2	2	50	2	3	2	6
Other health care facility								

Yes	2	2	0	0	2	3	0	0
No	95	96	2	50	65	94	32	94
Missing	2	2	2	50	2	3	2	6
Does not seek medical care under any circumstance								
Yes	4	4	0	0	4	6	0	0
No	93	94	2	50	63	91	32	94
Missing	2	2	2	50	2	3	2	6
Hobbies outside of work (auto repair or use of chemicals), %								
Yes	6	6	0	0	3	4	3	9
No	91	92	2	50	64	93	28	82
Missing	2	2	2	50	2	3	3	9
Had any pet that goes inside the home, %								
Yes	18	18		-	15	22	3	9
No	29	29		-	23	33	6	18
Missing	52	52		-	31	45	25	74
Lived on same property as an IHO, %								
Yes	8	8	0	0	7	10	1	3
No	87	88	2	50	58	84	31	91
Missing	4	4	2	50	4	6	2	6

[a]Categories are not mutually exclusive.

Table M2.2. Summary of results from Bland-Altman plots at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

	n	Mean difference Koko - Piko-1 (95% CI)	Intercept (b_0)	Slope (b_1)
FEV_1 (L)				
All	68	0.17 (0.05, 0.29)	0.20	-0.01
ATS-valid	35	0.34 (0.22, 0.45)	0.16	0.06
PEFr (L/s)				
All	68	-0.73 (-1.28, -0.18)	-1.85	0.16
ATS-valid	17	0.09 (0.46, 0.63)	-0.88	0.15
Asthmatics				
FEV_1 (L)	7	0.27 (0.07, 0.46)	-0.01	0.10
PEFr (L/s)	8	-0.41 (-1.46, 0.63)	-2.67	0.34

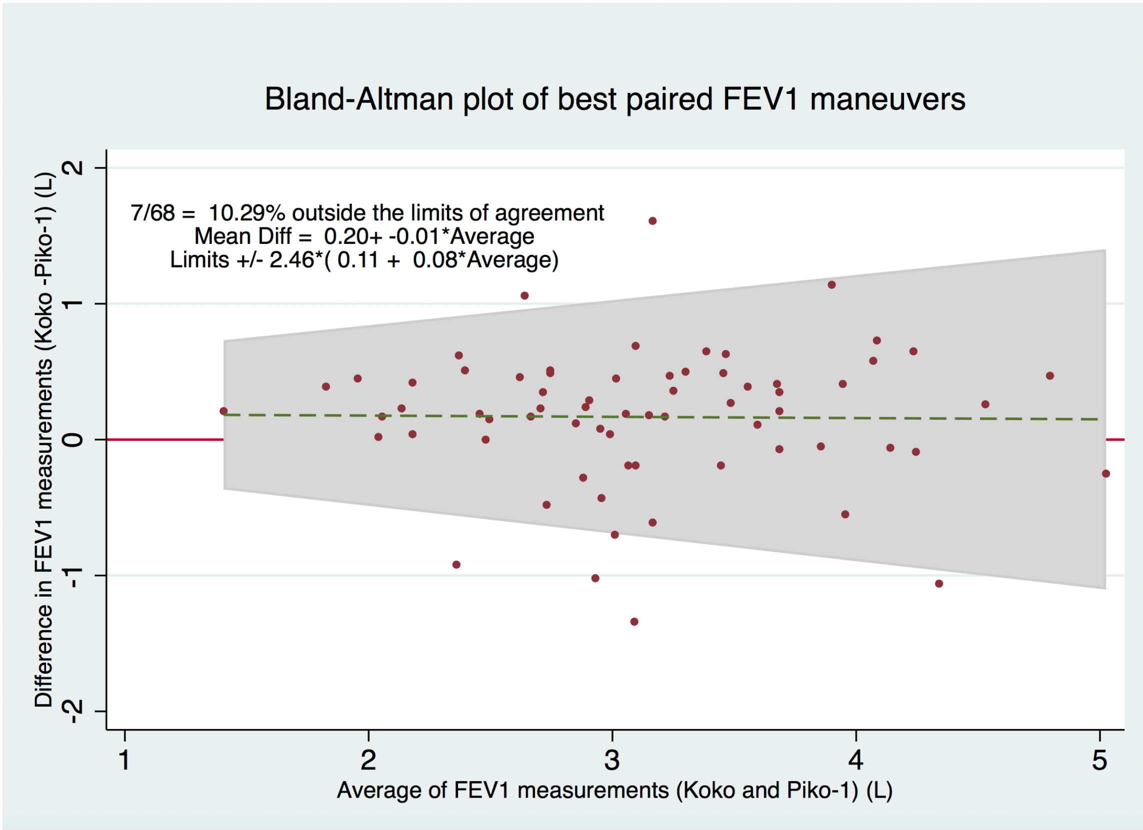

Figure M2.1. Bland-Altman plot of all paired Piko-1 and Koko FEV_1 (L) measurements at baseline (intercept=0.20; slope= -0.01) in the IHO worker cohort, North Carolina 2013-2014.

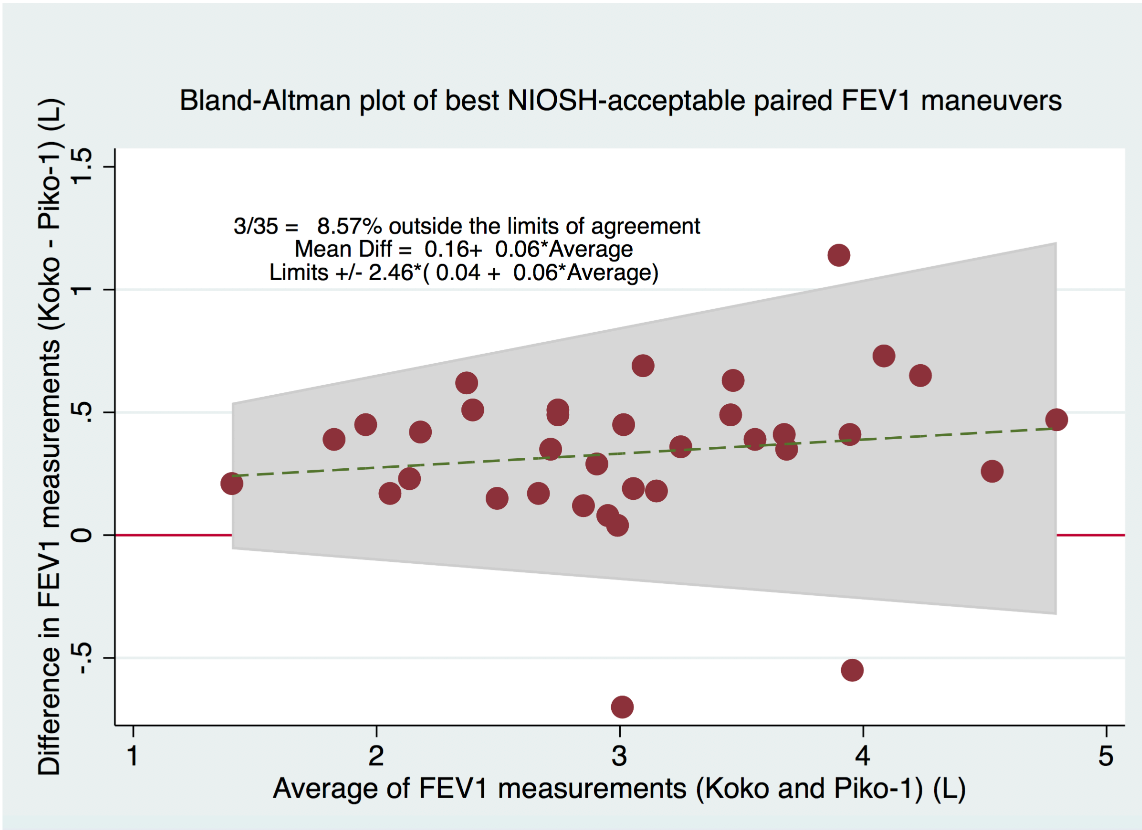

Figure M2.2. Bland-Altman plot of only NIOSH-acceptable Piko-1 and Koko FEV_1 (L) measurements at baseline (intercept=0.16; slope=0.06) in the IHO worker cohort, North Carolina 2013-2014.

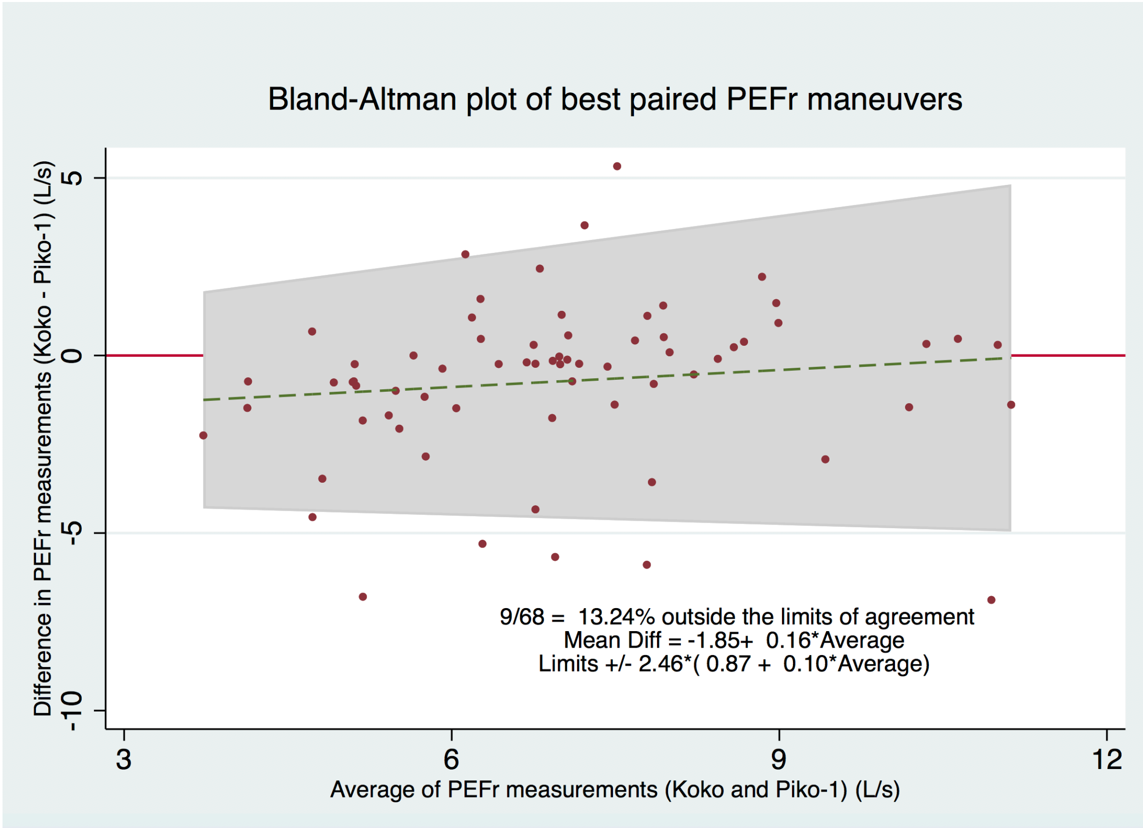

Figure M2.3. Bland-Altman plot of all paired Piko-1 and Koko PEFr (L/s) measurements at baseline (intercept= -1.85; slope=0.16) in the IHO worker cohort, North Carolina 2013-2014.

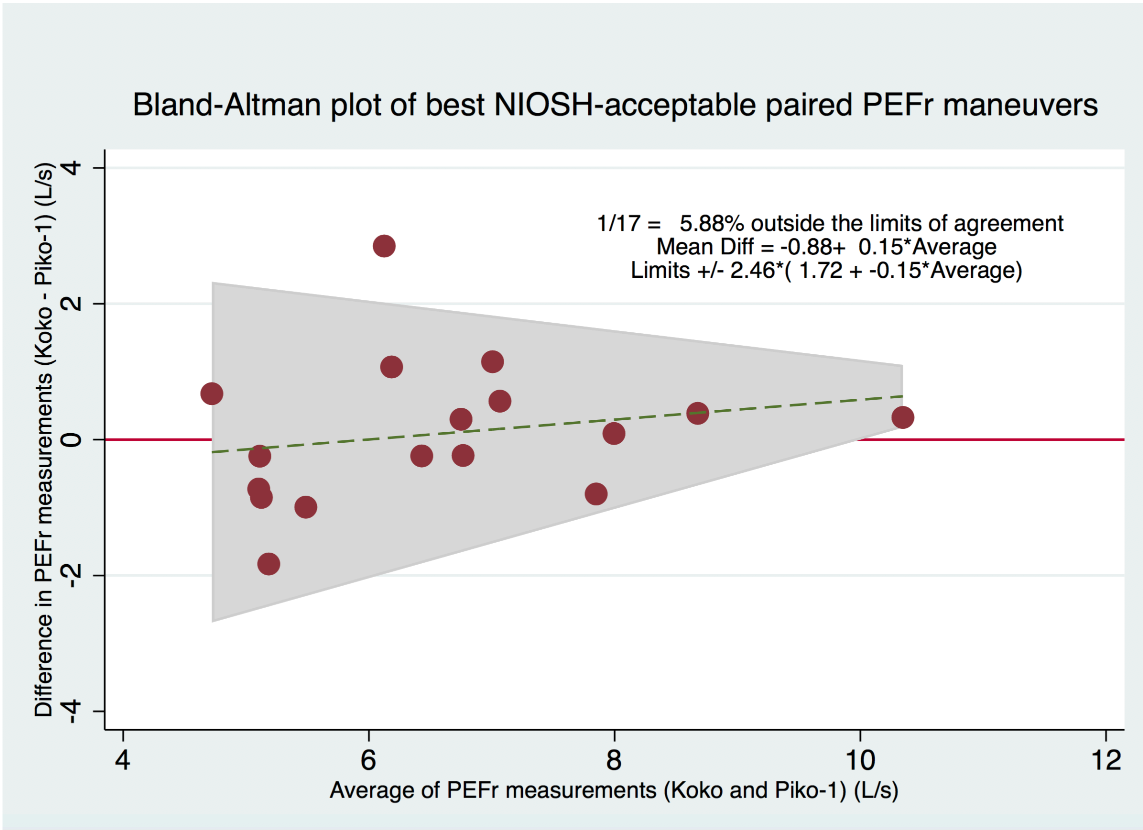

Figure M2.4. Bland-Altman plot of only NIOSH-acceptable Piko-1 and Koko PEFr (L/s) measurements at baseline (intercept= -0.88; slope=0.15) in the IHO worker cohort, North Carolina 2013-2014.

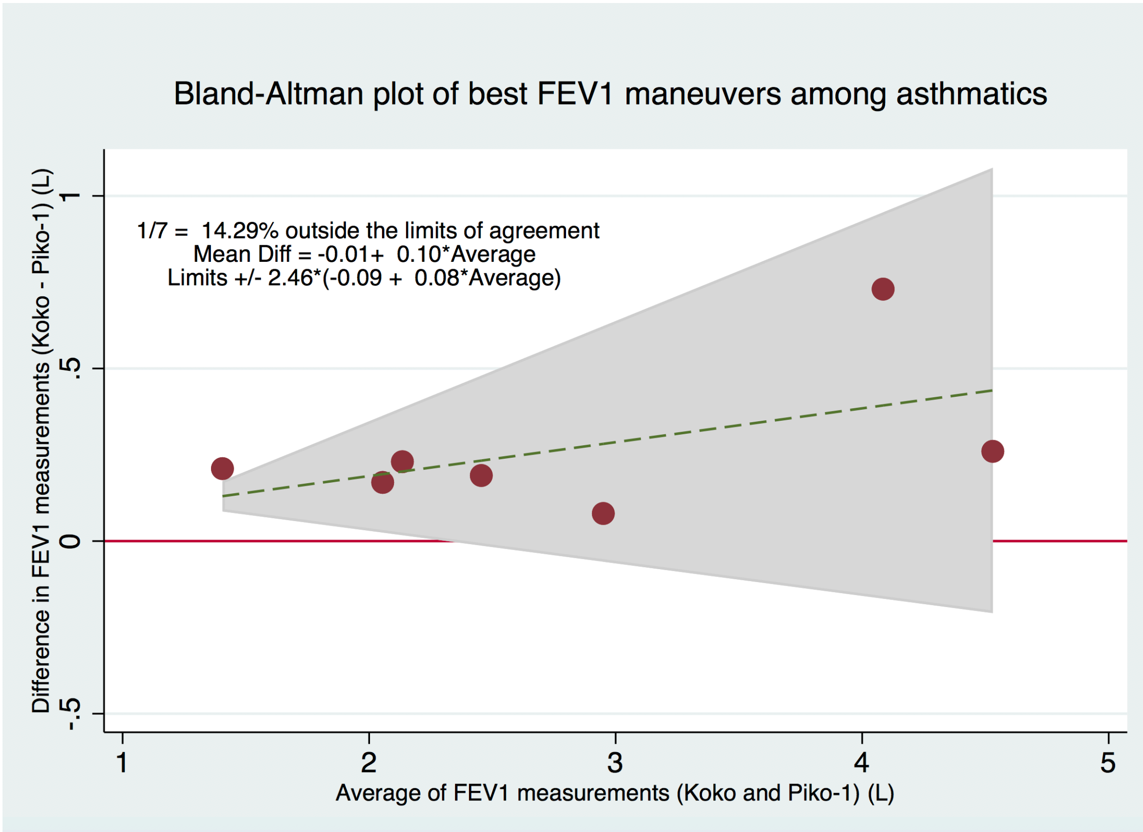

Figure M2.5. Bland-Altman plot of Piko-1 and Koko FEV1 (L) measurements at baseline among doctor-diagnosed asthmatics in an IHO worker cohort, North Carolina 2013-2014.

Table M2.3. Classifying pulmonary function tests for two spirometers by the National Institute for Occupational Safety and Health (NIOSH) criteria for valid tests within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

	Koko, n (%)	**Piko-1, n (%)**
FEV_1 (L)		
Three tries		
Yes	68 (99)	799 (90)
No	1 (1)	86 (10)
<0.15L apart		
Yes	61 (90)	500 (67)
No	7 (10)	385 (44)
FVC (L)		
Three tries		
Yes	68 (99)	-
No	1 (1)	-
<0.15L apart		
Yes	56 (81)	-
No	13 (19)	-
PEFr (L/s)		
Three tries		
Yes	68 (66)	799 (95)
No	35 (34)	38 (5)
<0.67L apart		
Yes	38 (56)	439 (53)
No	30 (44)	391 (47)

Table M2.4. Classification of adverse respiratory outcomes based on spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014, using NIOSH-acceptable data.

Characteristic	n	%
GOLD (via Koko)		
Obstructive		
No	50	100
Yes	0	0
Restrictive		
No	50	100
Yes	0	0
Lower limit of normal (LLN)		
Obstructive (via Koko)		
No	58	100
Yes	0	0
Obstructive (via Piko-1)		
No	47	90
Yes	5	10
Restrictive (via Koko)		
No	67	100
Yes	0	0

Normal = FEV_1 and FVC above 80% predicted (LLN); FEV_1/FVC ratio above 0.7 (GOLD)
Obstructive = FEV_1 below 80% predicted (LLN); FEV_1/FVC ratio below 0.7 (GOLD)
Restrictive = FVC below 80% predicted (LLN); FEV_1/FVC ratio normal, above 0.7 (GOLD)

Table M2.5a. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level, using NIOSH-acceptable spirometric tests.

	% Predicted FEV$_1$[a]			% Predicted FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	56	1.61 (-9.23, 12.45)		53	0.51 (-8.58, 9.61)	
Drawn pigs blood	56	3.42 (-21.43, 28.28)		53	1.49 (-18.25, 21.22)	
Handled pig manure	56	2.26 (-6.55, 11.07)		53	-1.70 (-10.54, 7.13)	
Applied pesticides in or around the barns	56	0.99 (-7.74, 9.73)		53	1.60 (-6.44, 9.64)	
Washed work clothes with household laundry	55	-0.54 (-16.54, 15.46)		53	-1.43 (-14.47, 11.61)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	55	1.76 (-7.69, 11.22)		51	2.46 (-6.53, 11.45)	
Work exclusively in feeder and/or finisher barns	55	-2.71 (-11.31, 5.89)		51	-2.11 (-10.56, 6.34)	
Always wear a mask and bodysuit and eye protection	55	7.06 (-0.59, 14.71)		52	0.82 (-9.49, 11.12)	
Worked seven days per week	56	1.40 (-7.39, 10.18)		53	4.08 (-3.97, 12.14)	
100% of time at work spent in direct contact with hogs	55	-9.74 (-19.70, 0.22)		53	-6.27 (-15.27, 2.73)	
Years worked on an IHO						
Tertile 1 (1-5 years)	53	Ref (0.0)	0.067	50	Ref (0.0)	0.213
Tertile 2 (6-10 years)		-7.17 (-17.50, 3.16)			-8.56 (-19.11, 1.99)	
Tertile 3 (11-27 years)		-10.11 (-21.19, 0.97)			-6.52 (-16.83, 3.80)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	53	Ref (0.0)	0.315	50	Ref (0.0)	0.842
Tertile 2 (11.7-26.3%)		**-12.35 (-22.80, -1.89)**			-5.87 (-17.94, 6.20)	
Tertile 3 (26.4-51.9%)		-6.45 (-18.19, 5.29)			-1.79 (-14.83, 11.25)	

[a]Performed on a Koko spirometer

Table M2.5b. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level, using NIOSH-acceptable spirometric tests.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	34	-25.99 (-52.82, 0.85)		47	**4.13 (0.31, 7.95)**	
Drawn pigs blood	34	-0.44 (-32.51, 31.63)		47	1.25 (-3.49, 6.19)	
Handled pig manure	34	1.98 (-23.94, 27.90)		47	0.93 (-2.73, 4.58)	
Applied pesticides in or around the barns	34	-11.54 (-35.10, 12.01)		47	1.49 (-2.04, 5.03)	
Washed work clothes with household laundry	34	4.47 (-36.60, 45.54)		47	-1.40 (-5.88, 3.08)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	34	18.06 (-6.11, 42.23)		46	1.20 (-2.13, 4.52)	
Work exclusively in feeder and/or finisher barns	34	-21.14 (-47.30, 5.02)		46	-0.53 (-4.20, 3.14)	
Always wear a mask and bodysuit and eye protection	33	**21.96 (1.98, 41.93)**		46	2.25 (-2.14, 6.65)	
Worked seven days per week	34	-14.57 (-42.75, 13.61)		47	-1.06 (-4.28, 2.16)	
100% of time at work spent in direct contact with hogs	33	-10.27 (-36.39, 15.85)		47	-0.73 (-4.68, 3.22)	
Years worked on an IHO						
Tertile 1 (1-5 years)	33	Ref (0.0)	0.539	44	Ref (0.0)	0.494
Tertile 2 (6-10 years)		-13.84 (-46.31, 18.62)			-3.32 (-7.47, 0.83)	
Tertile 3 (11-27 years)		-7.81 (-33.58, 17.95)			-1.15 (-4.90, 2.60)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	33	Ref (0.0)	0.602	44	Ref (0.0)	0.354
Tertile 2 (11.7-26.3%)		**-35.59 (-61.92, -9.27)**			**-5.58 (-9.12, -2.05)**	
Tertile 3 (26.4-51.9%)		0.88 (-23.37, 25.12)			-2.44 (-6.58, 1.71)	

[a]Performed on a Koko spirometer

Table M2.5c. Crude baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM and clustered at the household level, using NIOSH-acceptable spirometric tests.

	Piko-1					
	% Predicted FEV_1			% Predicted PEFr		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	50	2.77 (-7.30, 12.83)		50	20.14 (-1.80, 42.08)	
Drawn pigs blood	50	0.71 (-14.93, 16.34)		51	-4.29 (-36.85, 28.27)	
Handled pig manure	48	-2.38 (-16.06, 11.29)		47	-20.00 (-52.39, 12.39)	
Applied pesticides in or around the barns	50	-7.56 (-19.06, 3.94)		51	-1.23 (-26.54, 24.09)	
Washed work clothes with household laundry	49	-3.66 (-20.86, 13.55)		49	-4.07 (-22.88, 14.73)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	48	2.87 (-9.11, 14.86)		49	7.63 (-18.92, 34.18)	
Work exclusively in feeder and/or finisher barns	48	-9.40 (-21.58, 2.78)		49	-18.32 (-50.01, 13.38)	
Always wear a mask and bodysuit and eye protection	49	-1.69 (-11.80, 8.41)		50	**32.17 (5.28, 59.06)**	
Worked 7 days per week	50	8.38 (-1.95, 18.71)		51	**-31.62 (-54.73, -8.50)**	
100% of time at work spent in direct contact with hogs	49	-6.18 (-16.72, 4.35)		48	10.73 (-13.41, 34.87)	
Years worked on an IHO						
Tertile 1 (1-5 years)	45	Ref (0.0)	0.056	45	Ref (0.0)	0.827
Tertile 2 (6-10 years)		-9.92 (-24.18, 4.34)			-16.35 (-45.78, 15.08)	
Tertile 3 (11-27 years)		-13.46 (-27.25, 0.33)			-2.54 (-32.75, 27.66)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	45	Ref (0.0)	0.081	44	Ref (0.0)	0.911
Tertile 2 (11.7-26.3%)		**-19.76 (-34.95, -4.57)**			**-35.96 (-71.30, -0.61)**	
Tertile 3 (26.4-51.9%)		-14.22 (-29.37, 0.93)			-4.31 (-37.46, 28.84)	

Table M2.6a. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level and NIOSH-acceptable tests.

	% Predicted FEV_1[a]			% Predicted FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	54	3.72 (-7.58, 15.02)		52	1.78 (-6.80, 10.35)	
Drawn pigs blood	54	3.37 (-19.60, 26.33)		52	1.60 (-16.71, 19.91)	
Handled pig manure	54	2.96 (-6.13, 12.04)		52	-0.96 (-10.17, 8.25)	
Applied pesticides in or around the barns	54	1.84 (-6.79, 10.48)		52	3.37 (-4.64, 11.39)	
Washed work clothes with household laundry	53	1.03 (-14.65, 16.70)		52	0.28 (-12.53, 13.10)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	53	-1.42 (-11.40, 8.57)		50	-0.06 (-8.88, 8.75)	
Work exclusively in feeder and/or finisher barns	53	0.15 (-8.62, 8.92)		50	0.25 (-7.79, 8.28)	
Always wear a mask and bodysuit and eye protection	53	6.11 (-2.72, 14.94)		51	-0.13 (-13.40, 13.14)	
Worked 7 days per week	54	2.87 (-6.21, 11.95)		52	5.38 (-3.10, 13.86)	
100% of time at work spent in direct contact with hogs	54	-8.99 (-18.56, 0.57)		52	-5.90 (-14.60, 2.81)	
Years worked on an IHO						
Tertile 1 (1-5 years)	51	Ref (0.0)	0.086	49	Ref (0.0)	0.259
Tertile 2 (6-10 years)		-2.77 (-14.44, 8.91)			-3.21 (-14.19, 7.78)	
Tertile 3 (11-27 years)		-9.07 (-19.44, 1.31)			-5.51 (-15.10, 4.08)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	51	Ref (0.0)	0.533	49	Ref (0.0)	0.929
Tertile 2 (11.7-26.3%)		-6.66 (-18.63, 5.32)			3.11 (-7.81, 14.04)	
Tertile 3 (26.4-51.9%)		-4.14 (-15.43, 7.15)			0.95 (-10.54, 12.44)	

[a]Performed on a Koko spirometer

Table M2.6b. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level and NIOSH-acceptable tests.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	32	-16.66 (-50.27, 16.95)		46	**5.16 (1.71, 8.61)**	
Drawn pigs blood	32	-4.61 (-30.83, 21.62)		46	1.36 (-3.00, 5.72)	
Handled pig manure	32	10.33 (-11.38, 32.04)		46	0.98 (-2.62, 4.58)	
Applied pesticides in or around the barns	32	-9.98 (-32.60, 12.65)		46	2.10 (-1.34, 5.54)	
Washed work clothes with household laundry	32	8.55 (-24.20, 41.29)		46	-1.24 (-5.52, 3.03)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	32	8.21 (-15.05, 31.48)		45	0.24 (-3.10, 3.57)	
Work exclusively in feeder and/or finisher barns	32	-5.20 (-30.93, 20.53)		45	0.30 (-2.96, 3.56)	
Always wear a mask and bodysuit and eye protection	31	32.15 (-7.17, 71.47)		45	2.19 (-1.33, 5.70)	
Worked 7 days per week	32	-10.45 (-34.74, 13.83)		46	-0.50 (-3.51, 2.51)	
100% of time at work spent in direct contact with hogs	32	-10.08 (-33.22, 13.06)		46	-0.48 (-4.30, 3.35)	
Years worked on an IHO						
Tertile 1 (1-5 years)	31	Ref (0.0)	0.507	43	Ref (0.0)	0.732
Tertile 2 (6-10 years)		-10.29 (-39.00, 18.41)			-3.38 (-7.61, 0.84)	
Tertile 3 (11-27 years)		-8.46 (-33.71, 16.78)			-0.53 (-4.51, 3.44)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	31	Ref (0.0)	0.755	43	Ref (0.0)	0.481
Tertile 2 (11.7-26.3%)		-21.91 (-54.00, 10.19)			**-7.35 (-11.04, -3.65)**	
Tertile 3 (26.4-51.9%)		0.79 (-22.51, 24.10)			-2.70 (-6.77, 1.38)	

[a]Performed on a Koko spirometer

Table M2.6c. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level and NIOSH-acceptable tests.

	% Predicted FEV_1[a]			% Predicted PEFr[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	40	3.60 (-6.24, 13.44)		35	21.89 (-6.99, 50.78)	
Drawn pigs blood	40	4.01 (-10.81, 18.82)		35	0.50 (-24, 57, 25.56)	
Handled pig manure	39	-1.36 (-14.00, 11.28)		34	-19.82 (-52.75, 13.11)	
Applied pesticides in or around the barns	40	-1.29 (-11.51, 8.92)		35	-22.19 (-55.77, 11.40)	
Washed work clothes with household laundry	39	0.91 (-16.98, 18.79)		34	0.35 (-22.72, 23.41)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	38	-4.24 (-15.58, 7.11)		34	-13.33 (-44.59, 17.93)	
Work exclusively in feeder and/or finisher barns	38	-5.18 (-14.96, 4.59)		34	-5.00 (-28.27, 18.26)	
Always wear a mask and bodysuit and eye protection	39	2.08 (-9.17, 13.34)		34	24.63 (-2.48, 51.74)	
Worked 7 days per week	40	7.58 (-1.34, 16.50)		35	**-42.64 (-69.19, -16.09)**	
100% of time at work spent in direct contact with hogs	40	-4.61 (-14.83, 5.61)		35	19.03 (-10.33, 48.39)	
Years worked on an IHO						
Tertile 1 (1-5 years)	36	Ref (0.0)	0.177	31	Ref (0.0)	0.821
Tertile 2 (6-10 years)		2.61 (-11.20, 16.42)			-1.05 (-37.04, 34.95)	
Tertile 3 (11-27 years)		-8.80 (-22.02, 4.43)			-4.60 (-42.13, 32.94)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	36	Ref (0.0)	0.478	31	Ref (0.0)	0.532
Tertile 2 (11.7-26.3%)		-11.50 (-27.78, 4.77)			-35.08 (-90.17, 20.02)	
Tertile 3 (26.4-51.9%)		-6.73 (-21.00, 7.53)			-17.55 (-62.39, 27.29)	

[a]Performed on a Piko-1 spirometer

Table M2.7a. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable spirometric tests.

	% Predicted FEV_1[a]			**% Predicted FVC[a]**		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	54	4.39 (-7.41, 16.18)		52	2.02 (-7.04, 11.08)	
Drawn pigs blood	54	4.39 (-17.01, 25.79)		52	3.94 (-12.04, 19.91)	
Handled pig manure	54	5.86 (-3.34, 15.06)		52	2.47 (-6.50, 11.45)	
Applied pesticides in or around the barns	54	0.007 (-7.71, 7.72)		52	2.11 (-5.28, 9.51)	
Washed work clothes with household laundry	53	3.08 (-13.21, 19.38)		52	4.39 (-8.48, 17.25)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	53	-0.51 (-10.37, 9.36)		50	0.36 (-8.49, 9.21)	
Work exclusively in feeder and/or finisher barns	53	-1.46 (-10.44, 7.51)		50	-2.69 (-11.37, 5.98)	
Always wear a mask and bodysuit and eye protection	53	7.13 (-1.17, 15.43)		51	1.33 (-10.36, 13.03)	
Worked 7 days per week	54	-0.04 (-9.45, 9.38)		52	2.16 (-6.92, 11.24)	
100% of time at work spent in direct contact with hogs	54	**-9.61 (-19.04, -0.19)**		52	-6.57 (-14.40, 1.26)	
Years worked on an IHO						
Tertile 1 (1-5 years)	50	Ref (0.0)	0.118	48	Ref (0.0)	0.427
Tertile 2 (6-10 years)		-3.29 (-14.07, 7.48)			-4.33 (-14.10, 5.44)	
Tertile 3 (11-27 years)		-9.02 (-20.50, 2.46)			-4.23 (-15.38, 6.92)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	50	Ref (0.0)	0.612	48	Ref (0.0)	0.768
Tertile 2 (11.7-26.3%)		-7.19 (-19.80, 5.41)			1.88 (-9.23, 12.99)	
Tertile 3 (26.4-51.9%)		-3.67 (-15.17, 7.82)			1.92 (-9.75, 13.60)	

[a]Performed on a Koko spirometer

Table M2.7b. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable spirometric tests.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	32	-19.34 (-53.07, 14.39)		46	**4.85 (1.42, 8.29)**	
Drawn pigs blood	32	-4.45 (-35.20, 26.30)		46	0.66 (-4.49, 5.80)	
Handled pig manure	32	9.74 (-13.13, 32.61)		46	0.45 (-3.38, 4.27)	
Applied pesticides in or around the barns	32	-8.28 (-31.48, 14.92)		46	2.46 (-0.95, 5.87)	
Washed work clothes with household laundry	32	12.16 (-17.22, 41.54)		46	-1.97 (-6.87, 2.92)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	32	6.77 (-17.16, 30.70)		45	0.06 (-3.27, 3.40)	
Work exclusively in feeder and/or finisher barns	32	-4.56 (-30.32, 21.20)		45	0.78 (-2.70, 4.25)	
Always wear a mask and bodysuit and eye protection	31	32.53 (-7.39, 72.44)		45	1.83 (-1.59, 2.26)	
Worked 7 days per week	32	-9.93 (-35.95, 16.09)		46	0.51 (-2.79, 3.82)	
100% of time at work spent in direct contact with hogs	32	-11.88 (-35.22, 11.45)		46	-0.42 (-4.05, 3.21)	
Years worked on an IHO						
Tertile 1 (1-5 years)	30	Ref (0.0)	0.573	42	Ref (0.0)	0.879
Tertile 2 (6-10 years)		-15.47 (-45.07, 14.13)			-2.95 (-7.00, 1.11)	
Tertile 3 (11-27 years)		-7.39 (-34.03, 19.25)			0.07 (-4.22, 4.36)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	30	Ref (0.0)	0.814	42	Ref (0.0)	0.617
Tertile 2 (11.7-26.3%)		-23.28 (-55.03, 8.48)			**-7.33 (-11.00, -3.65)**	
Tertile 3 (26.4-51.9%)		0.31 (-24.39, 25.02)			-2.36 (-6.45, 1.74)	

[a]Performed on a Koko spirometer

Table M2.7c. Hour of test (continuous), current smoker (binary), and interviewer (dummy)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable spirometric tests.

	% Predicted FEV_1[a]			% Predicted PEFr[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	39	3.38 (-8.33, 15.09)		34	**25.86 (1.27, 50.46)**	
Drawn pigs blood	39	4.98 (-9.65, 19.61)		34	-0.96 (-37.85, 35.93)	
Handled pig manure	38	-1.03 (-14.26, 12.19)		33	-21.29 (-52.28, 9.70)	
Applied pesticides in or around the barns	39	-2.02 (-12.23, 8.19)		34	-22.29 (53.21, 8.62)	
Washed work clothes with household laundry	38	-1.01 (-16.74, 14.72)		33	9.97 (-21.60, 41.55)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	38	-4.62 (-16.20, 6.96)		33	-12.09 (-42.31, 18.13)	
Work exclusively in feeder and/or finisher barns	38	-4.65 (-15.89, 6.58)		33	-5.35 (-29.75, 19.06)	
Always wear a mask and bodysuit and eye protection	38	5.51 (-7.12, 18.14)		33	2.22 (-33.01, 37.45)	
Worked 7 days per week	39	7.45 (-1.79, 16.69)		34	**-36.08 (-58.75, -13.40)**	
100% of time at work spent in direct contact with hogs	39	-4.19 (-14.10, 5.72)		34	14.71 (-12.49, 41.90)	
Years worked on an IHO						
Tertile 1 (1-5 years)	35	Ref (0.0)	0.089	30	Ref (0.0)	0.934
Tertile 2 (6-10 years)		0.69 (-11.21, 12.59)			6.34 (-22.10, 34.78)	
Tertile 3 (11-27 years)		-10.54 (-23.28, 2.19)			-2.42 (-36.49, 31.64)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	35	Ref (0.0)	0.278	30	Ref (0.0)	0.727
Tertile 2 (11.7-26.3%)		-14.44 (-31.19, 2.31)			**-27.03 (-71.80, 17.73)**	
Tertile 3 (26.4-51.9%)		-10.08 (-24.67, 4.52)			-11.53 (-52.18, 29.13)	

[a]Performed on a Piko-1 spirometer

Table M2.8a. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using all spirometric tests.

	% Predicted FEV_1[a]			% Predicted FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	63	0.73 (-8.67, 10.14)		63	-1.13 (-9.77, 7.52)	
Drawn pigs blood	63	5.05 (-18.09, 28.18)		63	1.37 (-16.68, 19.42)	
Handled pig manure	63	1.58 (-6.96, 10.12)		63	1.56 (-7.75, 10.87)	
Applied pesticides in or around the barns	63	1.34 (-6.73, 9.42)		63	-2.89 (-11.49, 5.72)	
Washed work clothes with household laundry	62	2.56 (-8.54, 13.67)		62	1.03 (-9.84, 11.89)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	61	-0.94 (-9.99, 8.11)		61	-1.63 (-10.28, 7.02)	
Work exclusively in feeder and/or finisher barns	61	-1.59 (-10.33, 7.14)		61	0.19 (-8.55, 8.94)	
Always wear a mask and bodysuit and eye protection	62	3.61 (-7.24, 14.47)		62	3.60 (-9.10, 16.29)	
Worked 7 days per week	63	1.78 (-6.50, 10.06)		63	2.56 (-6.00, 11.12)	
100% of time at work spent in direct contact with hogs	63	-5.91 (-14.43, 2.62)		63	-6.41 (-14.94, 2.11)	
Years worked on an IHO						
Tertile 1 (1-5 years)	60	Ref (0.0)	0.064	60	Ref (0.0)	0.059
Tertile 2 (6-10 years)		-6.77 (-17.12, 3.57)			-5.37 (-16.30, 5.55)	
Tertile 3 (11-27 years)		-8.74 (-17.91, 0.43)			-9.41 (-19.14, 0.33)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	60	Ref (0.0)	0.512	60	Ref (0.0)	0.554
Tertile 2 (11.7-26.3%)		-8.76 (-19.90, 2.38)			-3.63 (-15.99, 8.73)	
Tertile 3 (26.4-51.9%)		-4.34 (-14.39, 5.71)			-3.64 (-15.08, 7.79)	

[a]Performed on a Koko spirometer

Table M2.8b. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using all spirometric tests.

	% Predicted PEFr[a]			% Predicted FEV_1/FVC[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	62	-23.28 (-46.69, 0.13)		63	2.85 (-0.53, 6.24)	
Drawn pigs blood	62	6.65 (-16.44, 29.75)		63	1.87 (-2.89, 6.63)	
Handled pig manure	62	8.61 (-12.18, 29.40)		63	-0.09 (-3.45, 3.28)	
Applied pesticides in or around the barns	62	8.39 (-12.26, 29.05)		63	**4.28 (0.82, 7.73)**	
Washed work clothes with household laundry	61	15.43 (-8.18, 39.03)		62	1.26 (-2.70, 5.22)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	60	-2.80 (-23.37, 17.77)		61	1.20 (-1.91, 4.31)	
Work exclusively in feeder and/or finisher barns	60	-2.58 (-23.59, 18.43)		61	-1.97 (-6.02, 2.08)	
Always wear a mask and bodysuit and eye protection	61	-3.71 (-42.83, 35.40)		62	-0.10 (-4.02, 3.83)	
Worked 7 days per week	62	-13.38 (-34.58, 7.82)		63	-1.19 (-4.22, 1.83)	
100% of time at work spent in direct contact with hogs	62	6.36 (-11.91, 24.63)		63	0.750 (-2.95, 4.45)	
Years worked on an IHO						
Tertile 1 (1-5 years)	59	Ref (0.0)	0.609	60	Ref (0.0)	0.124
Tertile 2 (6-10 years)		-6.68 (-32.55, 19.19)			-1.85 (-7.17, 3.46)	
Tertile 3 (11-27 years)		-7.05 (-34.09, 20.00)			0.23 (-3.05, 3.51)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	59	Ref (0.0)	0.822	60	Ref (0.0)	0.618
Tertile 2 (11.7-26.3%)		-6.98 (-36.29, 22.33)			**-5.99 (-10.89, -1.09)**	
Tertile 3 (26.4-51.9%)		2.46 (-28.35, 33.28)			-1.77 (-5.68, 2.13)	

[a]Performed on a Koko spirometer

Table M2.8c. Hour of test (continuous) and current smoker (binary)-adjusted baseline relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using all spirometric tests.

	% Predicted FEV_1[a]			% Predicted PEFr[a]		
	n	ß (95% CI)	p for trend	n	ß (95% CI)	p for trend
Have you ever						
Given pigs shots and/or antibiotics	71	4.37 (-6.84, 15.58)		74	2.32 (-19.59, 24.22)	
Drawn pigs blood	71	0.08 (-13.81, 13.97)		74	1.27 (-17.28, 19.81)	
Handled pig manure	70	-2.75 (-11.97, 6.48)		73	-4.09 (-22.64, 14.46)	
Applied pesticides in or around the barns	71	-0.65 (-9.02, 7.73)		74	-7.85 (-26.22, 10.52)	
Washed work clothes with household laundry	70	-1.61 (-14.24, 11.02)		73	11.54 (-10.27, 33.34)	
Do you typically						
Work exclusively in sow, nursery, and/or farrow barns	68	-5.39 (-14.44, 3.67)		71	-12.51 (-30.75, 5.73)	
Work exclusively in feeder and/or finisher barns	68	1.71 (-6.62, 10.07)		71	-3.60 (-18.22, 11.02)	
Always wear a mask and bodysuit and eye protection	70	4.12 (-4.25, 12.49)		73	9.61 (-7.20, 26.41)	
Worked 7 days per week	71	1.22 (-6.92, 9.35)		74	**-24.57 (-40.22, -8.91)**	
100% of time at work spent in direct contact with hogs	71	5.81 (-15.24, 3.62)		74	-1.74 (-20.27, 16.80)	
Years worked on an IHO						
Tertile 1 (1-5 years)	65	Ref (0.0)	0.327	68	Ref (0.0)	0.692
Tertile 2 (6-10 years)		5.27 (-7.31, 17.85)			8.97 (-14.09, 32.02)	
Tertile 3 (11-27 years)		-5.38 (-15.68, 4.92)			-4.85 (-27.10, 17.40)	
Percent of life working on an IHO						
Tertile 1 (2.4-11.6%)	65	Ref (0.0)	0.225	66	Ref (0.0)	0.558
Tertile 2 (11.7-26.3%)		-6.33 (-19.80, 7.14)			-17.22 (-47.34, 12.90)	
Tertile 3 (26.4-51.9%)		-6.51 (-16.71, 3.69)			-8.67 (-33.62, 16.27)	

[a]Performed on a Piko-1 spirometer

Table M2.9a. Crude relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		% Predicted FVC [a]		% Predicted PEFr [a]		% Predicted FEV_1/FVC [a]	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	55	2.98 (-8.77, 14.74)	52	**9.53 (0.14, 18.92)**	33	-6.39 (-30.62, 17.83)	46	-0.87 (-4.34, 2.61)
Any allergies	57	-10.83 (-28.02, 6.36)	54	-5.89 (-18.60, 6.81)	35	**-53.10 (-66.10, -40.10)**	48	-0.22 (-6.94, 6.51)
Doctor-diagnosed asthma	58	**-12.84 (-25.30, -0.37)**	55	-7.90 (-21.96, 6.16)	36	1.06 (-30.66, 32.78)	49	-1.06 (-4.37, 2.24)

[a]Performed on a Koko spirometer

Table M2.9b. Crude relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		**% Predicted PEFr [a]**	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	49	-2.63 (-13.26, 8.00)	50	9.24 (-10.39, 28.87)
Any allergies	51	**-15.84 (-26.42, -5.27)**	51	13.94 (-23.68, 51.56)
Doctor-diagnosed asthma	52	-9.86 (-21.32, 1.59)	52	1.50 (-14.51, 17.51)

[a]Performed on a Piko-1 spirometer

Table M2.10a. Hour of test (continuous)- and current cigarette smoking (binary)- adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		**% Predicted FVC [a]**		**% Predicted PEFr [a]**		**% Predicted FEV_1/FVC [a]**	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	53	7.64 (-4.21, 19.49)	51	**13.36 (3.93, 22.78)**	31	12.87 (-16.46, 42.20)	45	0.22 (-3.58, 4.01)
Any allergies	54	-13.30 (-27.07, 0.48)	52	-7.88 (-18.60, 2.84)	32	**-45.43 (-58.79, -32.07)**	46	-1.21 (-6.69, 4.28)
Doctor-diagnosed asthma	55	-12.25 (-29.56, 5.06)	53	-4.78 (-22.16, 12.59)	33	14.69 (-24.98, 54.36)	47	-1.55 (-4.17, 1.07)

[a]Performed on a Koko spirometer

Table M2.10b. Hour of test (continuous)- and current cigarette smoking (binary)- adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		**% Predicted PEFr [a]**	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	39	1.52 (-9.36, 12.40)	34	0.05 (-21.05, 21.14)
Any allergies	40	**-12.68 (-23.37, -2.00)**	35	**38.81 (10.37, 67.25)**
Doctor-diagnosed asthma	41	-8.21 (-24.16, 7.75)	36	10.24 (-13.36, 33.84)

[a]Performed on a Piko-1 spirometer

Table M2.11a. Hour of test (continuous)-, current cigarette smoking (binary)-, and interviewer (dummy) adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level and only NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		**% Predicted FVC [a]**		**% Predicted PEFr [a]**		**% Predicted FEV_1/FVC [a]**	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	53	6.04 (-5.11, 17.19)	51	**11.32 (3.19, 19.46)**	31	13.94 (-14.99, 42.87)	45	0.66 (-3.10, 4.41)
Any allergies	54	**-15.22 (-29.82, -0.62)**	52	**-9.57 (-18.46, -0.67)**	32	**-45.15 (-60.33, -29.98)**	46	-1.06 (-5.87, 3.75)
Doctor-diagnosed asthma	54	-11.59 (-30.02, 6.84)	52	-1.19 (-17.62, 15.23)	32	10.16 (-42.20, 62.52)	46	-2.94 (-6.00, 0.11)

[a]Performed on a Koko spirometer

Table M2.11b. Hour of test (continuous)-, current cigarette smoking (binary)-, and interviewer (dummy) adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level and only NIOSH-acceptable maneuvers.

	% Predicted FEV_1 [a]		% Predicted PEFr [a]	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	38	-2.34 (-12.36, 7.67)	33	14.99 (-6.31, 36.30)
Any allergies	39	**-18.26 (-29.76, -6.76)**	34	**29.57 (4.96, 54.18)**
Doctor-diagnosed asthma	39	-9.42 (-31.73, 12.89)	34	15.48 (-4.59, 35.55)

[a]Performed on a Piko-1 spirometer

Table M2.12a. Hour of test (continuous)- and current cigarette smoking (binary)- adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using all spirometry tests.

	% Predicted FEV_1 [a]		% Predicted FVC [a]		% Predicted PEFr [a]		% Predicted FEV_1/FVC [a]	
	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	62	7.87 (-2.32, 18.06)	62	6.90 (-2.87, 16.66)	61	4.30 (-13.74, 22.34)	62	-0.48 (-3.81, 2.84)
Any allergies	63	**-13.55 (-25.14, -1.96)**	63	**-13.43 (-25.72, -1.13)**	62	-19.19 (-44.77, 6.39)	63	-0.06 (-4.38, 4.27)
Doctor-diagnosed asthma	64	-10.46 (-27.56, 6.63)	64	-9.97 (-27.69, 7.74)	63	9.29 (-20.56, 39.14)	64	-0.68 (-3.69, 2.33)

[a]Performed on a Koko spirometer

Table M2.12b. Hour of test (continuous)- and current cigarette smoking (binary)-adjusted relationship between occupational activities and spirometry measurements at baseline within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GLM clustered at the household level, using all spirometry tests.

	% Predicted FEV_1 [a]		% Predicted PEFr [a]	
	n	ß (95% CI)	n	ß (95% CI)
Eye, nose, or throat symptoms	70	3.64 (-5.44, 12.72)	74	-1.10 (-16.68, 14.47)
Any allergies	71	-3.90 (-20.43, 12.63)	74	16.23 (-11.17, 43.62)
Doctor-diagnosed asthma	72	-10.34 (-22.78, 2.09)	76	1.60 (-14.30, 17.49)

[a]Performed on a Piko-1 spirometer

Table M2.13. Month (dummy)-, hour of test (dummy)- and smoked in the past 12 hours (binary)-adjusted longitudinal relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects linear regression and NIOSH-acceptable data.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	404 (96)	-0.03 (-0.18, 0.11)	352 (93)	-0.29 (-0.84, 0.26)
Performed a cleaning activity[b]	414 (96)	0.08 (-0.07, 0.22)	358 (94)	-0.21 (-0.79, 0.37)
Pig contact[c]	413 (96)	-0.07 (-0.22, 0.07)	360 (95)	-0.18 (-0.75, 0.39)
Performed two or three of the above[d]	399 (96)	0.01 (-0.14, 0.15)	347 (93)	-0.07 (-0.66, 0.52)
Used any protection consistently[e]	411 (96)	-0.10 (-0.39, 0.21)	357 (95)	**-2.04 (-3.38, -0.70)**
Handwashing at least 8 times per shift[f]	409 (96)	**0.15 (0.02, 0.28)**	355 (95)	**0.63 (0.10, 1.16)**

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f]8 is the median.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and an ATS-acceptable spirometry test result.

Table M2.14. Month (dummy)-, hour of test (dummy)- and smoked in the past 12 hours (binary)-, and interviewer (dummy)-adjusted longitudinal relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects linear regression and NIOSH-acceptable data.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	OR (95% CI)	obs. (workers)*	OR (95% CI)
Experienced some form of dustiness or odor[a]	404 (96)	-0.04 (-0.18, 0.11)	352 (93)	-0.33 (-0.89, 0.23)
Performed a cleaning activity[b]	414 (96)	0.08 (-0.06, 0.22)	358 (94)	-0.16 (-0.75, 0.43)
Pig contact[c]	413 (96)	-0.07 (-0.22, 0.07)	360 (95)	-0.15 (-0.73, 0.43)
Performed two or three of the above[d]	399 (96)	0.02 (-0.13, 0.16)	347 (93)	-0.03 (-0.63, 0.57)
Used any protection consistently[e]	411 (96)	-0.09 (-0.39, 0.20)	357 (95)	**-2.03 (-3.37, -0.69)**
Handwashing at least 8 times per shift[f]	409 (96)	**0.15 (0.02, 0.28)**	355 (95)	**0.66 (0.12, 1.19)**

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f]8 is the median.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and an ATS-acceptable spirometry test result.

Table M2.15. Month (dummy)-, hour of test (dummy)-, and smoked in the past 12 hours (binary)-adjusted longitudinal relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects linear regression and all data.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	691 (99)	-0.02 (-0.17, 0.14)	691 (99)	-0.05 (-0.46, 0.35)
Performed a cleaning activity[b]	711 (99)	0.05 (-0.10, 0.20)	711 (99)	0.01 (-0.39, 0.40)
Pig contact[c]	708 (100)	-0.10 (-0.25, 0.06)	708 (100)	-0.23 (-0.64, 0.18)
Performed two or three of the above[d]	679 (99)	0.03 (-0.13, 0.19)	679 (99)	-0.005 (-0.42, 0.41)
Used any protection consistently[e]	703 (100)	**-0.30 (-0.56, -0.04)**	703 (100)	**-0.85 (-1.55, -0.15)**
Handwashing at least 8 times per shift[f]	707 (100)	0.05 (-0.10, 0.19)	707 (100)	0.23 (-15, 0.60)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f]8 is the median.

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a Piko-1 spirometry test result.

Table M2.16. Crude longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by mask usage (above or below 80%), North Carolina, 2013-2014, using fixed-effects regression and NIOSH-acceptable spirometry.

In the past week	Overall mask usage	FEV_1 (L)		PEFr (L/s)	
		obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	≥80%	169 (37)	0.02 (-0.19, 0.23)	161 (36)	0.46 (-0.22, 1.14)
	< 80%	241 (60)	-0.05 (-0.22, 0.13)	196 (57)	-0.62 (-1.28, 0.03)
Performed a cleaning activity[b]	≥80%	169 (37)	0.09 (-0.15, 0.34)	161 (36)	-0.29 (-1.09, 0.51)
	< 80%	251 (60)	0.05 (-0.12, 0.22)	202 (58)	0.03 (-0.69, 0.75)
Pig contact[c]	≥80%	168 (37)	0.13 (-0.13, 0.40)	161 (37)	0.43 (-0.41, 1.27)
	< 80%	251 (60)	-0.06 (-0.23, 0.10)	204 (58)	-0.45 (-1.13, 0.22)
Performed two or three of the above[d]	≥80%	168 (37)	0.08 (-0.17, 0.33)	160 (36)	0.13 (-0.64, 0.90)
	< 80%	237 (60)	0.01 (-0.16, 0.18)	192 (57)	-0.11 (-0.82, 0.61)
Used at least two forms of protection consistently[e]	≥80%	169 (37)	**0.32 (0.06, 0.57)**	162 (37)	-0.68 (-1.56, 0.20)
	< 80%	247 (60)	-0.09 (-0.31, 0.14)	199 (58)	0.87 (-0.22, 1.97)
Handwashing at least 8 times per shift[f]	≥80%	169 (37)	0.002 (-0.22, 0.22)	162 (37)	0.50 (-0.25, 1.26)
	< 80%	246 (60)	**0.26 (0.10, 0.42)**	198 (58)	0.59 (-0.06, 1.23)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore two of the following: mask, glasses, or bodysuit/coveralls
[f]8 is the median

CI = confidence interval.
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.17. Month (dummy)-, hour of test (dummy)-, and smoked in the past 12 hours (binary)-adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by mask usage (above or below 80%), North Carolina, 2013-2014, using fixed-effects regression and NIOSH-acceptable spirometry.

In the past week	Overall mask usage	FEV_1 (L)		PEFr (L/s)	
		obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	≥80%	168 (37)	0.04 (-0.17, 0.25)	161 (36)	0.41 (-0.42, 1.24)
	< 80%	236 (59)	0.00 (-0.21, 0.21)	191 (57)	-0.81 (-1.69, 0.08)
Performed a cleaning activity[b]	≥80%	168 (37)	0.05 (-0.22, 0.31)	161 (36)	-0.27 (-1.29, 0.74)
	< 80%	246 (59)	0.07 (-0.10, 0.25)	197 (58)	-0.13 (-0.94, 0.69)
Pig contact[c]	≥80%	167 (37)	-0.07 (-0.33, 0.19)	161 (37)	0.38 (-0.56, 1.33)
	< 80%	246 (59)	-0.09 (-0.27, 0.10)	199 (58)	-0.46 (-1.23, 0.31)
Performed two or three of the above[d]	≥80%	167 (37)	-0.10 (-0.35, 0.15)	160 (36)	0.01 (-0.95, 0.97)
	< 80%	232 (59)	0.04 (-0.14, 0.22)	187 (57)	-0.07 (-0.91, 0.77)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.18. Month (dummy)-, hour of test (dummy)-, smoked in the past 12 hours (binary)-, and interviewer (dummy)-adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by mask usage (above or below 80%), North Carolina, 2013-2014, using fixed-effects regression and NIOSH-acceptable spirometry.

In the past week	Overall mask usage	**FEV_1 (L)**		**PEFr (L/s)**	
		obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	≥80%	168 (37)	0.04 (-0.17, 0.25)	161 (36)	0.25 (-0.59, 1.09)
	< 80%	236 (59)	0.00 (-0.22, 0.21)	191 (57)	-0.72 (-1.62, 0.18)
Performed a cleaning activity[b]	≥80%	168 (37)	0.06 (-0.21, 0.32)	161 (36)	-0.30 (-1.30, 0.70)
	< 80%	246 (59)	0.08 (-0.10, 0.26)	197 (58)	-0.16 (-0.99, 0.68)
Pig contact[c]	≥80%	167 (37)	-0.08 (-0.34, 0.18)	161 (37)	0.26 (-0.68, 1.20)
	< 80%	246 (59)	-0.09 (-0.28, 0.10)	199 (58)	-0.44 (-1.23, 0.34)
Performed two or three of the above[d]	≥80%	167 (37)	-0.09 (-0.35, 0.16)	160 (36)	-0.12 (-1.07, 0.83)
	< 80%	232 (59)	0.05 (-0.14, 0.23)	187 (57)	-0.06 (-0.92, 0.80)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval.
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.19. Crude longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by mask usage (above or below 80%), North Carolina, 2013-2014, using fixed-effects regression and all spirometry.

In the past week	Overall mask usage	obs. (workers)*	**FEV_1 (L)** ß (95% CI)	**PEFr (L/s)** ß (95% CI)
Experienced some form of dustiness or odor[a]	≥80%	279 (37)	0.03 (-0.20, 0.26)	-0.04 (-0.58, 0.51)
	< 80%	421 (62)	-0.10 (-0.28, 0.07)	-0.25 (-0.74, 0.24)
Performed a cleaning activity[b]	≥80%	280 (37)	-0.002 (-0.26, 0.25)	-0.41 (-1.01, 0.19)
	< 80%	440 (62)	0.07 (-0.11, 0.24)	0.22 (-0.27, 0.71)
Pig contact[c]	≥80%	280 (37)	0.06 (-0.25, 0.36)	0.39 (-0.33, 1.12)
	< 80%	438 (63)	-0.11 (-0.28, 0.06)	-0.32 (-0.79, 0.16)
Performed two or three of the above[d]	≥80%	278 (37)	0.04 (-0.23, 0.30)	-0.07 (-0.69, 0.55)
	< 80%	409 (62)	0.01 (-0.16, 0.19)	0.05 (-0.45, 0.54)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.20. Crude longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by handwashing at the median (above or below 8 times), North Carolina, 2013-2014, using fixed-effects regression and all spirometry.

In the past week	Overall handwashing	obs. (workers)*	**FEV_1 (L)** ß (95% CI)	**PEFr (L/s)** ß (95% CI)
Experienced some form of dustiness or odor[a]	≥8 times	322 (45)	-0.14 (-0.34, 0.07)	-0.12 (-0.65, 0.41)
	< 8 times	378 (54)	0.01 (-0.19, 0.20)	-0.23 (-0.74, 0.28)
Performed a cleaning activity[b]	≥8 times	331 (45)	-0.07 (-0.28, 0.13)	-0.23 (-0.76, 0.31)
	< 8 times	389 (54)	0.15 (-0.06, 0.35)	0.25 (-0.30, 0.78)
Pig contact[c]	≥8 times	333 (45)	-0.01 (-0.23, 0.21)	-0.12 (-0.71, 0.47)
	< 8 times	385 (55)	-0.11 (-0.31, 0.08)	-0.18 (-0.70, 0.35)
Performed two or three of the above[d]	≥8 times	321 (45)	-0.06 (-0.27, 0.15)	-0.25 (-0.80, 0.29)
	< 8 times	366 (54)	0.09 (-0.12, 0.29)	0.24 (-0.30, 0.78)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.21. Hour of test (continuous), month of test (dummy), smoked in the past 12 hours (binary), and interviewer (dummy)-adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by mask usage (above or below 80%), North Carolina, 2013-2014, using fixed-effects regression and all spirometry.

In the past week	Overall mask usage	obs. (workers)*	**FEV_1 (L)** ß (95% CI)	**PEFr (L/s)** ß (95% CI)
Experienced some form of dustiness or odor[a]	≥80%	278 (37)	0.13 (-0.11, 0.36)	0.17 (-0.40, 0.74)
	< 80%	413 (62)	-0.04 (-0.26, 0.17)	-0.09 (-0.68, 0.50)
Performed a cleaning activity[b]	≥80%	279 (37)	-0.02 (-0.29, 0.25)	-0.46 (-1.11, 0.19)
	< 80%	432 (62)	0.05 (-0.14, 0.23)	0.17 (-0.35, 0.69)
Pig contact[c]	≥80%	279 (37)	-0.05 (-0.24, 0.25)	0.19 (-0.54, 0.93)
	< 80%	429 (63)	-0.13 (-0.31, 0.05)	-0.36 (-0.87, 0.15)
Performed two or three of the above[d]	≥80%	277 (37)	-0.05 (-0.33, 0.23)	-0.26 (-0.92, 0.41)
	< 80%	402 (62)	0.04 (-0.16, 0.24)	0.08 (-0.46, 0.63)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.22. Hour of test (continuous), month of test (dummy), smoked in the past 12 hours (binary), and interviewer (dummy)-adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort stratified by handwashing at the median (above or below 8 times), North Carolina, 2013-2014, using fixed-effects regression and all spirometry.

In the past week	Overall handwashing	obs. (workers)*	**FEV_1 (L)** ß (95% CI)	**PEFr (L/s)** ß (95% CI)
Experienced some form of dustiness or odor[a]	≥8 times	319 (45)	-0.07 (-0.31, 0.16)	0.01 (-0.61, 0.63)
	< 8 times	372 (54)	-0.01 (-0.23, 0.20)	-0.29 (-0.84, 0.26)
Performed a cleaning activity[b]	≥8 times	329 (45)	-0.07 (-0.28, 0.15)	-0.20 (-0.78, 0.38)
	< 8 times	382 (54)	0.11 (-0.10, 0.33)	0.01 (-0.55, 0.57)
Pig contact[c]	≥8 times	330 (45)	-0.05 (-0.28, 0.19)	-0.24 (-0.87, 0.38)
	< 8 times	378 (55)	-0.18 (-0.40, 0.04)	-0.40 (-0.96, 0.18)
Performed two or three of the above[d]	≥8 times	319 (45)	-0.04 (-0.27, 0.19)	-0.23 (-0.83, 0.37)
	< 8 times	360 (54)	0.05 (-0.17, 0.28)	0.03 (-0.57, 0.62)

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c

CI = confidence interval
Green = associations are in the hypothesized direction
Red = associations are in the opposite direction as hypothesized

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.23. Crude relationship between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression and NIOSH-acceptable maneuvers.

In the past week	FEV_1 (L)		PEFr (L/s)	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
At least one respiratory symptom[a]	427 (98)	-0.24 (-0.49, 0.00)	371 (96)	**-1.40 (-2.40, -0.39)**
At least one symptom interfered with sleep[b]	423 (98)	-0.15 (-0.43, 0.13)	369 (96)	-0.92 (-2.05, 0.21)
Sneezing	428 (98)	-0.13 (-0.52, 0.25)	372 (96)	**-2.92 (-5.44, -0.40)**
Headache	428 (98)	-0.17 (-0.58, 0.24)	372 (96)	-1.67 (-3.44, 0.10)
Eye or nose irritation	428 (98)	0.04 (-0.49, 0.57)	372 (96)	0.68 (-2.74, 4.09)

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.24. Hour of test (dummy), month of test (dummy), smoked in the past 12 hours (binary), and interviewer (dummy)-between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression and NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
At least one respiratory symptom[a]	421 (98)	**-0.33 (-0.58, -0.07)**	366 (96)	**-1.31 (-2.38, -0.24)**
At least one symptom interfered with sleep[b]	416 (98)	-0.24 (-0.52, 0.04)	263 (96)	-0.81 (-1.99, 0.37)
Sneezing	422 (98)	-0.23 (-0.63, 0.18)	367 (96)	**-2.77 (-5.34, -0.19)**
Headache	422 (98)	-0.17 (-0.70, 0.37)	367 (96)	0.86 (-2.78, 4.51)
Eye or nose irritation	422 (98)	-0.26 (-0.68, 0.16)	367 (96)	-1.45 (-3.32, 0.42)

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.25. Month (dummy)-, cigarette smoked in the past 12 hours (binary)-, and time of test (dummy)-adjusted between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression and all spirometry data.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
At least one respiratory symptom[a]	722 (99)	**-0.30 (-0.55, -0.05)**	722 (99)	**-0.86 (-1.52, -0.20)**
At least one symptom interfered with sleep[b]	707 (99)	-0.18 (-0.49, 0.12)	707 (99)	-0.72 (-1.53, 0.10)
Sneezing	722 (99)	-0.13 (-0.53, 0.28)	722 (99)	-0.56 (-1.63, 0.50)
Headache	722 (99)	-0.14 (-0.53, 0.26)	722 (99)	0.71 (-1.76, 0.33)
Eye or nose irritation	722 (99)	-0.16 (-0.58, 0.26)	722 (99)	0.13 (-0.98, 1.24)

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm.

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.26. Month (dummy)-, cigarette smoked in the past 12 hours (binary)-, time of test (dummy)-, interviewer (dummy)-adjusted relationship between reported symptoms and spirometry measurements over time within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects regression and NIOSH-acceptable maneuvers.

In the past week	FEV$_1$ (L) obs. (workers)*	FEV$_1$ (L) ß (95% CI)	FEV$_1$ (L) p for trend	PEFr (L/s) obs. (workers)*	PEFr (L/s) ß (95% CI)	PEFr (L/s) p for trend
Dustiness score[a]						
0		Ref (0.0)			Ref (0.0)	
1	400 (96)	0.04 (-0.11, 0.19)	**0.047**	349 (93)	-0.18 (-0.75, 0.40)	0.054
2		**-0.22 (-0.41, -0.02)**			**-0.88 (-1.75, -0.002)**	
3 or 4		-0.15 (-0.47, 0.16)			-0.83 (-2.86, 1.20)	
Cleaning score[b]						
0		Ref (0.0)			Ref (0.0)	
1	414 (96)	0.04 (-0.12, 0.20)	0.121	358 (94)	-0.15 (-0.80, 0.50)	0.540
2		0.14 (-0.04, 0.31)			-0.09 (-0.80, 0.61)	
3 or 4		0.13 (-0.07, 0.33)			-0.30 (-1.10, 0.51)	
Pig contact score[c]						
0		Ref (0.0)			Ref (0.0)	
1	413 (96)	-0.13 (-0.29, 0.03)	0.897	360 (95)	-0.43 (-1.05, 0.20)	0.330
2		0.001 (-0.17, 0.17)			0.26 (-0.41, 0.93)	
All of the above[d]						
0		Ref (0.0)			Ref (0.0)	
1	399 (96)	-0.07 (-0.29, 0.15)	0.803	347 (93)	-0.37 (-1.18, 0.44)	0.309
2		-0.04 (-0.27, 0.19)			-0.24 (-1.12, 0.64)	
3		-0.06 (-0.33, 0.20)			-0.59 (-1.57, 0.39)	
PPE score[e,f]						
0		Ref (0.0)			Ref (0.0)	
1	411 (96)	-0.09 (-0.39, 0.21)	0.940	357 (95)	**-2.04 (-3.39, -0.69)**	0.595
2		-0.10 (-0.45, 0.24)			**-1.89 (-3.47, -0.31)**	
3		-0.06 (-0.45, 0.33)			**-1.70 (-3.40, -0.002)**	
Number of times washed hands per shift[g]	409 (96)		0.054	355 (95)		**0.001**

Tertile 1 (0-6)	Ref (0.0)	Ref (0.0)
Tertile 2 (7-10)	0.08 (-0.06, 0.22)	0.37 (-0.19, 0.93)
Tertile 3 (11-50)	0.19 (-0.003, 0.39)	**1.64 (0.78, 2.50)**

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or bodysuit/coveralls
[f]PPE = personal protective equipment.
[g]Tertiles

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.27. Crude longitudinal relationship between reported on-IHO exposures and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using fixed-effects linear regression and NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Experienced some form of dustiness or odor[a]	410 (97)	-0.03 (-0.16, 0.11)	357 (93)	-0.23 (-0.70, 0.25)
Performed a cleaning activity[b]	420 (97)	0.06 (-0.08, 0.20)	363 (94)	-0.08 (-0.61, 0.45)
Pig contact[c]	419 (97)	-0.02 (-0.16, 0.12)	365 (95)	-0.18 (-0.70, 0.34)
Performed two or three of the above[d]	405 (97)	0.03 (-0.11, 0.17)	352 (93)	-0.02 (-0.54, 0.50)
Used any protection consistently[e]	416 (97)	-0.20 (-0.47, 0.07)	361 (95)	**-1.39 (-2.57, -0.22)**
Handwashing at least 8 times per shift[f]	415 (97)	**0.17 (0.04, 0.30)**	360 (95)	**0.55 (0.07, 1.04)**

[a]Extreme temperature, extreme malodor, extreme dust, vents off, and/or a new herd entering the barns
[b]Used cleaning chemicals and/or pesticides, pressure washed and/or used a torch
[c]Gave pigs shots and/or medicine
[d]Summation of binary (yes/no) to a,b, and/or c
[e]Consistently (≥80% of the time at work) wore at least one of the following: mask, glasses, or full bodysuit/coveralls

*The number of observations equals the number of individual visits (1-8) for the number of persons (i.e., groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.28. Cross tabulations of personal protective equipment (PPE) and reported symptoms within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	**Coverall/ full body suit usage, n (%)**			**Mask usage, n (%)**			**Eye protection usage, n (%)**		
	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)
At least one respiratory symptom[a]									
No	148 (21)	541 (79)	0.709	353 (51)	335 (49)	0.365	516 (76)	167 (24)	0.344
Yes	8 (19)	34 (81)		19 (44)	24 (56)		29 (69)	13 (31)	
At least one symptom interfered with sleep[b]									
No	146 (21)	544 (79)	0.478	356 (52)	334 (48)	0.089	521 (76)	163 (24)	**0.002**
Yes	4 (15)	22 (85)		9 (35)	17 (65)		13 (50)	13 (50)	
Sneezing									
No	152 (21)	564 (79)	0.919	368 (51)	347 (49)	0.087	541 (76)	169 (24)	**<0.001**
Yes	4 (22)	14 (78)		6 (32)	13 (68)		7 (39)	11 (61)	
Headache									
No	151 (21)	568 (79)	0.248	368 (51)	351 (49)	0.391	537 (75)	176 (25)	0.860
Yes	5 (33)	10 (67)		6 (40)	9 (60)		11 (73)	4 (27)	
Eye or nose symptoms									
No	153 (21)	567 (79)	0.987	368 (51)	351 (49)	0.391	539 (75)	175 (25)	0.336
Yes	3 (21)	11 (79)		6 (40)	9 (60)		9 (64)	5 (36)	

[a]Excessive coughing, runny nose, difficulty breathing, or sore throat.
[b]Any sleep symptoms reported, waking from sleep due to coughing, waking from sleep due to wheezing, or waking from sleep due to phlegm

Table M2.29. Cross tabulations of personal protective equipment (PPE) and work conditions within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014.

In the past week	Coverall/ full body suit usage, n (%)			Mask usage, n (%)			Eye protection usage, n (%)		
	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)	<80%	≥80%	*p*-value (Pearson X^2)
Barn conditions score[a]									
0	53 (15)	298 (85)		127 (36)	224 (64)		220 (63)	130 (37)	
1	74 (33)	148 (67)	**<0.001**	133 (60)	89 (40)	**<0.001**	196 (89)	24 (11)	**<0.001**
2 or more	21 (16)	112 (84)		91 (67)	44 (33)		110 (83)	23 (17)	
Cleaning score[b]									
0	57 (25)	172 (75)		116 (51)	113 (49)		153 (68)	73 (32)	
1	57 (31)	125 (69)	**<0.001**	98 (54)	85 (46)	0.583	160 (88)	22 (12)	**<0.001**
2 or more	41 (13)	272 (87)		153 (49)	161 (51)		228 (73)	84 (27)	
Pig contact score[c]									
0	84 (27)	223 (73)		159 (52)	149 (48)		222 (73)	82 (27)	
1	28 (12)	203 (88)	**<0.001**	99 (43)	133 (57)	**0.002**	162 (70)	69 (30)	**0.001**
2	42 (23)	142 (77)		110 (60)	74 (40)		156 (85)	27 (15)	
Score components[d]									
0 or 1	40 (25)	121 (75)		69 (43)	91 (57)		105 (66)	55 (34)	
2 or 3	66 (22)	233 (78)	0.158	142 (47)	158 (53)	**0.033**	226 (76)	71 (24)	**0.009**
4, 5, or 6	40 (17)	193 (83)		131 (56)	104 (44)		184 (79)	49 (21)	
Number of times washed hands per shift									
Tertile 1 (0-6)	70 (23)	239 (77)		174 (56)	137 (44)		237 (77)	71 (23)	
Tertile 2 (7-10)	70 (21)	267 (79)	0.531	146 (43)	190 (57)	**0.001**	235 (71)	98 (29)	**0.007**
Tertile 3 (11-50)	14 (21)	68 (83)		49 (60)	33 (40)		71 (87)	11 (13)	

[a]Sum of extreme temperature (yes=1, no=0), extreme malodor (yes=1, no=0), extreme dust (yes=1, no=0), vents off (yes=1, no=0), and a new herd entering the barn(s) (yes=1, no=0)
[b]Sum of used cleaning chemicals (yes=1, no=0), used pesticides (yes=1, no=0), pressure washed (yes=1, no=0), and used a torch (yes=1, no=0)
[c]Sum of gave pigs shots (yes=1, no=0) and gave pigs medicine (yes=1, no=0)
[d]Number of individual activities/conditions (maximum 10)

Table M2.30. Crude longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GEE c(ar1), using NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Number of days worked	94 (18)	0.10 (0.01, 0.19)	86 (18)	-0.14 (-0.47, 0.20)
Number of hours worked (per 10)	94 (18)	0.01 (-0.11, 0.13)	86 (18)	-0.17 (-0.58, 0.23)
Direct contact hours (per 10)	94 (18)	0.01 (-0.07, 0.10)	86 (18)	-0.13 (-0.48, 0.22)
Number of sick hogs (per 100)	89 (17)	0.02 (-0.02, 0.05)	86 (18)	-0.04 (-0.15, 0.07)
Number of dead hogs (per 100)	89 (17)	0.01 (-0.03, 0.05)	86 (18)	-0.01 (-0.11, 0.08)
Number of times washed hands at the IHO	93 (18)	0.00 (-0.02, 0.02)	85 (18)	-0.06 (-0.14, 0.03)
% of time a mask was used (per 10%)	94 (18)	0.01 (-0.02, 0.03)	88 (19)	0.05 (-0.05, 0.14)
% of time coveralls worn (per 10%)	94 (18)	0.01 (-0.02, 0.05)	88 (19)	-0.05 (-0.16, 0.07)
% of time eye protection used (per 10%)	93 (18)	0.00 (-0.03, 0.03)	88 (19)	0.02 (-0.08, 0.11)
Used chemicals	94 (18)	-0.04 (-0.21, 0.13)	85 (18)	0.05 (-0.56, 0.66)
Gave pigs shot	84 (16)	-0.02 (-0.23, 0.19)	82 (17)	-0.40 (-1.18, 0.38)
Pressure washed	88 (17)	-0.14 (-0.38, 0.11)	85 (18)	0.20 (-0.50, 0.90)
Gave pigs medicine	89 (17)	0.11 (-0.09, 0.31)	86 (18)	-0.08 (-0.69, 0.53)
Used pesticides in or around barns	89 (17)	0.22 (0.01, 0.42)	86 (18)	-0.14 (-0.73, 0.45)
Extreme malodor in barns	94 (18)	-0.10 (-0.31, 0.11)	88 (19)	-0.03 (-0.71, 0.64)
Vent fans off	89 (17)	0.23 (-0.08, 0.53)	88 (19)	**-0.86 (-1.69, -0.02)**
Extreme dust in barns	94 (18)	0.22 (-0.23, 0.67)	88 (19)	0.11 (-1.84, 2.06)
Extreme temperature in barns	93 (18)	0.15 (-0.12, 0.41)	87 (19)	-1.18 (-2.39, 0.03)

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.31. Crude longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GEE c(exchangeable), using NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Number of days worked	430 (98)	0.02 (-0.04, 0.07)	374 (96)	0.09 (-0.08, 0.27)
Number of hours worked (per 10)	422 (97)	0.04 (-0.02, 0.09)	367 (95)	0.06 (-0.14, 0.26)
Direct contact hours (per 10)	422 (97)	0.04 (-0.01, 0.09)	367 (95)	0.06 (-0.11, 0.22)
Number of sick hogs (per 100)	422 (97)	0.01 (-0.02, 0.03)	367 (95)	0.04 (-0.06, 0.14)
Number of dead hogs (per 100)	422 (97)	0.01 (-0.02, 0.05)	366 (95)	0.02 (-0.09, 0.14)
Number of times washed hands at the IHO	416 (97)	**0.02 (0.01, 0.03)**	361 (95)	**0.09 (0.07, 0.11)**
% of time a mask was used (per 10%)	418 (97)	0.00 (-0.01, 0.02)	363 (95)	**0.06 (0.00, 0.11)**
% of time coveralls worn (per 10%)	419 (97)	0.01 (-0.01, 0.03)	364 (95)	-0.01 (-0.07, 0.05)
% of time eye protection used (per 10%)	416 (97)	0.01 (0.00, 0.03)	361 (95)	0.05 (-0.01, 0.10)
Used chemicals	420 (97)	0.06 (-0.06, 0.19)	364 (95)	0.15 (-0.25, 0.56)
Gave pigs shot	421 (97)	0.05 (-0.07, 0.18)	366 (95)	0.21 (-0.23, 0.64)
Pressure washed	421 (97)	**0.23 (0.10, 0.36)**	365 (95)	0.21 (-0.24, 0.65)
Gave pigs medicine	420 (97)	-0.01 (-0.13, 0.11)	366 (95)	0.03 (-0.36, 0.41)
Used pesticides in or around barns	423 (97)	0.11 (-0.01, 0.23)	367 (94)	-0.15 (-0.55, 0.26)
Extreme malodor in barns	419 (97)	-0.07 (-0.20, 0.06)	365 (95)	**-0.54 (-1.01, -0.07)**
Vent fans off	418 (97)	-0.10 (-0.27, 0.06)	364 (95)	**-0.60 (-1.15, -0.04)**
Extreme dust in barns	420 (97)	0.14 (-0.16, 0.44)	365 (95)	0.10 (-1.09, 1.29)
Extreme temperature in barns	410 (97)	-0.06 (-0.27, 0.14)	357 (94)	-0.34 (-1.00, 0.32)

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.32. Age-, sex-, race-, height (cm^2)- adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GEE c(ar1), using NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Number of days worked	81 (15)	0.06 (-0.03, 0.15)	77 (16)	-0.21 (-0.59, 0.18)
Number of hours worked (per 10)	81 (15)	-0.05 (-0.16, 0.07)	77 (16)	-0.10 (-0.56, 0.35)
Direct contact hours (per 10)	81 (15)	-0.01 (-0.10, 0.08)	77 (16)	-0.14 (-0.54, 0.26)
Number of sick hogs (per 100)	76 (14)	0.01 (-0.03, 0.04)	77 (16)	-0.03 (-0.15, 0.09)
Number of dead hogs (per 100)	76 (14)	0.00 (-0.04, 0.04)	77 (16)	-0.01 (-0.12, 0.10)
Number of times washed hands at the IHO	74 (14)	0.01 (-0.02, 0.03)	76 (16)	-0.08 (-0.18, 0.02)
% of time a mask was used (per 10%)	81 (15)	0.02 (0.00, 0.05)	79 (17)	0.08 (-0.02, 0.17)
% of time coveralls worn (per 10%)	81 (15)	**0.03 (0.00, 0.07)**	79 (17)	-0.02 (-0.15, 0.11)
% of time eye protection used (per 10%)	80 (15)	0.02 (-0.01, 0.05)	79 (17)	0.03 (-0.08, 0.14)
Used chemicals	75 (14)	-0.05 (-0.24, 0.13)	76 (16)	0.21 (-0.48, 0.91)
Gave pigs shot	76 (14)	0.05 (-0.16, 0.27)	77 (16)	-0.25 (-1.07, 0.58)
Pressure washed	75 (14)	0.01 (-0.24, 0.26)	76 (16)	0.18 (-0.58, 0.95)
Gave pigs medicine	76 (14)	0.09 (-0.11, 0.30)	77 (16)	-0.24 (-0.94, 0.45)
Used pesticides in or around barns	76 (14)	0.17 (-0.03, 0.38)	79 (17)	-0.10 (-0.75, 0.56)
Extreme malodor in barns	81 (15)	-0.15 (-0.37, 0.06)	77 (16)	-0.04 (-0.82, 0.73)
Vent fans off	76 (14)	0.09 (-0.20, 0.39)	79 (17)	**-0.97 (-1.92, -0.02)**
Extreme dust in barns	81 (15)	0.26 (-0.20, 0.72)	79 (17)	-0.48 (-2.56, 1.60)
Extreme temperature in barns	80 (15)	0.08 (-0.19, 0.35)	78 (17)	-1.22 (-2.63, 0.19)

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Table M2.33. Age-, sex-, race-, height (cm^2)- adjusted longitudinal relationship between reported physical symptoms and measured lung function within an industrial hog operation (IHO) worker cohort, North Carolina, 2013-2014 using GEE c(exchangeable), using NIOSH-acceptable maneuvers.

In the past week	**FEV_1 (L)**		**PEFr (L/s)**	
	obs. (workers)*	ß (95% CI)	obs. (workers)*	ß (95% CI)
Number of days worked	392 (89)	0.01 (-0.04, 0.06)	342 (87)	0.08 (-0.11, 0.27)
Number of hours worked (per 10)	384 (88)	0.04 (-0.01, 0.09)	335 (86)	0.07 (-0.14, 0.28)
Direct contact hours (per 10)	384 (88)	0.05 (0.00, 0.09)	335 (86)	0.06 (-0.12, 0.25)
Number of sick hogs (per 100)	384 (88)	0.01 (-0.02, 0.03)	335 (86)	0.04 (-0.06, 0.15)
Number of dead hogs (per 100)	384 (88)	0.02 (-0.02, 0.05)	334 (86)	0.03 (-0.10, 0.15)
Number of times washed hands at the IHO	379 (88)	**0.02 (0.01, 0.03)**	330 (86)	**0.09 (0.06, 0.11)**
% of time a mask was used (per 10%)	380 (88)	0.01 (-0.01, 0.02)	331 (86)	**0.08 (0.02, 0.13)**
% of time coveralls worn (per 10%)	381 (88)	0.01 (-0.01, 0.02)	332 (86)	-0.05 (-0.12, 0.01)
% of time eye protection used (per 10%)	378 (88)	0.01 (0.00, 0.03)	329 (86)	0.04 (-0.02, 0.10)
Used chemicals	383 (88)	0.12 (0.00, 0.24)	335 (86)	0.27 (-0.17, 0.71)
Gave pigs shot	384 (88)	0.09 (-0.03, 0.22)	335 (86)	0.17 (-0.29, 0.63)
Pressure washed	383 (88)	**0.24 (0.12, 0.37)**	333 (86)	0.20 (-0.28, 0.67)
Gave pigs medicine	382 (88)	-0.01 (-0.13, 0.10)	334 (86)	0.00 (-0.42, 0.41)
Used pesticides in or around barns	385 (88)	0.12 (0.00, 0.23)	336 (86)	-0.17 (-0.59, 0.26)
Extreme malodor in barns	381 (88)	-0.09 (-0.22, 0.04)	333 (86)	**-0.69 (-1.21, -0.16)**
Vent fans off	380 (88)	-0.15 (-0.30, 0.01)	332 (86)	**-0.71 (-1.29, -0.13)**
Extreme dust in barns	382 (88)	0.11 (-0.21, 0.42)	333 (86)	-0.62 (-1.94, 0.70)
Extreme temperature in barns	373 (88)	-0.07 (-0.27, 0.13)	325 (85)	-0.31 (-1.03, 0.40)

*The number of observations equals the number of individual visits (1-8) for the number of persons (*i.e.,* groups) with both a response to the symptom question and a NIOSH-acceptable Piko-1 spirometry test result.

Chapter 3

Table M3.1. Characteristics of industrial hog operation (IHO) workers in a community-driven research (CDR) pilot project, North Carolina 2017-2018 versus those industrial hog operation (IHO) workers in a prior cohort, North Carolina 2013-2014.

	Aims 1 and 2 (paper surveys)		**Aim 3 (electronic surveys)**	
Characteristic	**Reports, n**	**Mean (SD)**	**Reports, n**	**Mean (SD)**
Workers in cohort	103	-	18	-
Age in years	97	38 (11)	17	41 (12)
Missing	6	-	1	-
Height in centimeters	96	165 (11)	-	-
Missing	7	-	-	-
Weight in pounds	96	172 (32)	-	-
Missing	7	-	-	-
Characteristic	**Reports, n**	**%**	**Reports, n**	**%**
Sex				
Male	55	53	6	33
Female	46	45	12	67
Missing	2	2	0	0
Race/ethnicity				
Hispanic, non-black	88	85	10	33
Black	12	12	6	56
Other	0	0	2	11
Missing	3	3	0	0
Education status				
Less than high school education	47	46	4	22
High school degree/GED or higher or other	52	50	14	78
Missing	4	4	0	0
Body mass index (BMI)				
<30.0	58	56	-	-
≥30.0	38	37	-	-
Missing	7	7	-	-
Used a gym or workout facility in the last three months				
Yes	9	9	1	6
No	92	90	17	94
Missing	2	2	0	0
Current cigarette smoker				
Yes	13	13	3	17

No	65	63	15	83
Missing	25	24	0	0
Health insurance				
Yes	48	47	12	67
No	52	50	6	33
Missing	3	3	0	0
Place where IHO workers seek medical care[a]				
Private doctor	49	48	7	39
Emergency department or urgent care center	29	28	7	39
Hospital	18	17	4	22
Free clinic	16	16	7	39
Other	3	3	2	11
Does not seek medical care under any circumstance	4	4	0	0
Missing	4	4	0	0
Hobbies outside of work (auto repair or use of chemicals)				
Yes	6	6	-	-
No	92	89	-	-
Missing	5	5	-	-
Had a cat or dog				
Yes	44	43	4	22
No	50	48	7	39
Missing	9	9	7	39
Lived on same property as an IHO				
Yes	8	8	0	0
No	89	86	18	100
Missing	6	6	0	0
Season of visit				
Winter	51	50	7	39
Fall	52	50	3	17
Spring	0	0	8	44
Missing	0	0	0	0
Month of baseline visit				
January	1	1	4	22
February	50	49	1	6
March	0	0	6	33
April	0	0	4	22
October	30	29	0	0
November	22	21	1	6
Missing	0	0	0	0

Table M3.2. Characteristics of mask usage among industrial hog operation (IHO) workers in a community-driven research (CDR) pilot project, North Carolina 2017-2018.

	Reports, n (%)
Mask usage	
Always	10 (53)
Sometimes	9 (47)
Type of mask	
N95	17 (89)
Surgical	2 (11)
Does the employee take the mask home	
Yes	2 (11)
No	17 (89)
Employee trained in the proper use of a face mask at work	
Yes	15 (79)
No	4 (21)
Employer provided mask	
Yes	17 (89)
No	2 (11)
Type of mask provided[a]	
N95	15 (88)
Surgical	3 (18)
Respirator	0 (0)
Employer provided a face mask in the past two weeks	
Yes	16 (94)
No	1 (6)
Worker using the provided mask	
Yes	17 (100)
No	0 (0)

[a]Categories not mutually exclusive

DISCUSSION

Summary of Findings

This dissertation attempted to better characterize the role of industrial hog operation (IHO) activities on IHO worker health. It also conducted a pilot project taking previously used questions, plus a few new ones, and new molecular source tracking tools off-IHO to better quantify community exposure and health burdens potentially related to these facilities.

In Chapter 1, a cross-sectional and longitudinal analysis was conducted evaluating the association of IHO work activities and self-reported health outcomes in participants (n=103) from a worker cohort. Participants were recruited in 2013-2014 and followed for up to 16 weeks, reporting at visits every two weeks, via survey, IHO exposures and activities and personal health outcomes. At baseline, reports of ever *vs.* never drawing pig blood, applying pesticides, and increasing years worked at any IHO were positively associated with reports of mucus membrane irritation (eye, nose, and/or throat) symptoms. Working, on average, seven days per week (*vs.* less than seven days per week) was associated with decreased reports of eye, nose, and/or throat symptoms, any allergies, and asthma, a potential indication of healthy worker effect bias. Over time, transient exposures, including those associated with dustiness in barns, cleaning of barns, and pig contact were associated with increased odds of a variety of symptoms, particularly in the highest categories of exposure. Those who used *vs.* did not use personal protective equipment (PPE) had decreased odds of symptoms interfering with sleep (OR: 0.08; 95% CI: 0.01, 0.84) and eye or nose irritation (OR: 0.14; 95% CI: 0.02, 0.88).

In Chapter 2, cross-sectional and longitudinal analyses in the worker cohort was again conducted, this time evaluating the association of IHO work activities and spirometry measurements. As in Chapter 1, at baseline, typically working seven days per week versus less than seven indicated a protective effect, with better than expected lung function in workers who worked every day. However, lung function was also improved in those who reported giving pigs shots and/or medicine, ever using pesticides in or around the barns, and as years on the job increased. In Chapter 1, these associations showed an increase in eye, nose, and/or throat symptoms, which should lower lung function measures as well. Also counter to the results in Chapter 1, in longitudinal models increased PPE use was associated with diminished lung function. The donning of coveralls in increasingly worse barn conditions and with increased number of work tasks and the doffing of face protection under worse and numerous conditions appears to have driven this association.

In Chapter 3, lessons learned from a pilot study looking at at-home airborne exposures that traveled from IHOs, drawing participants from the same community as the worker cohort are reported. Using appropriate community-defined testing protocols capacity was built for the community partner organization, REACH. Light was also shed on lingering questions regarding on-IHO personal protective equipment (PPE). Technology was tailored to meet the needs of this particular community and this partnership has laid a road map for work of this nature in the future.

Together, the results suggest that in a healthy IHO worker population, typical and transient work activities were associated with self-reported mucus membrane and respiratory health outcomes, although these outcomes are not always in the same direction. It was also found that CDPR is an appropriate methodology to recruit and retain participants in hard-to-reach populations. Building long-lasting relationships with community partners enables both researchers and community leaders to propose and carry out critical research and build capacity for future work.

Strengths and Limitations

This dissertation benefitted from several strengths. The longitudinal worker cohort used in Chapters 1 and 2 had high participant retention, consistent variable collection, and strong support from the communities involved. By employing fixed-effects regression analyses to longitudinal data we were better able to control for time-invariant confounders than if we had used other generalized estimating equations. Additionally, the prospective nature of the worker cohort allowed for evaluation of changes in outcomes over time, leading to more robust conclusions in regard to directions of association. Further, enrollment was not limited to male workers, as in many past studies, but consisted of roughly half men (55%) and half women (45%). The greatest asset and strength of this research is the continued support and involvement from our community partner REACH. None of this research would have been possible without the community-based participatory research and community-driven questions from this group. They were key to enrolling participants and maintaining a relationship with a hard-to-reach population of Hispanic IHO workers, and they provided much-needed guidance throughout the research process.

As in all epidemiological studies, several limitations affected the results and interpretations of this thesis. Both cohorts are non-random, self-selected groups and this may lead to potential selection bias. That said, the recruited population reflects the demographics IHO workers in the Duplin, Sampson, and Bladen County areas.

Due to small numbers in baseline analyses few, if any, biologically-relevant confounders were supported, as problems with model convergence arose with the addition of confounders having even minimal missingness. Further, the small sample size of our baseline analyses makes the results highly sensitive to outliers.

Both cohorts lacked on-operation access; air sampling and personal monitoring could not be conducted on-site to corroborate survey answers. Further, these data are representative of IHO workers, who may represent a healthy-worker population. Healthy worker effect is a well-documented bias in many occupational settings. That said, one study of pig workers found that those who remained in pig farming longer had higher FEV_1 measurements than those who left, and the odds of quitting pig operations was increased for workers on farms with greater than 400 head of swine and lower than predicted initial lung function.[168] Further limitations in generalizability include the possible differences between warmer climates (North Carolina) and colder climates and concomitant differences in ventilation systems. No studies have compared the possible differences in temperature or humidity.[34]

Policy Implications and Future Research

Calls for research of this nature have been made by occupational health, environmental health, and environmental justice professionals. By adding to the literature and filling knowledge gaps we can begin to accurately provide guidance for policy changes to improve the lives of those living near and working in industrial hog operations.

Lack of prior consensus among occupational health experts in worker protection devices and timing has limited the regulations that can be promulgated for industry. In this work we have shown that PPE, both face protection and body protection, is beneficial and protective against report of respiratory symptoms, symptoms interfering with sleep, and eye and nose symptoms. Research from this dissertation has also shown that some IHOs are already providing N95 respirators. While it was reported that workers were more likely to don coveralls when tasks increased in number or dustiness/dirtiness, they were more likely to remove face protection.

Face protection (both eye and mask) is essential, and the analyses presented show that it is protective of mucus membrane and respiratory symptoms. This observation is consistent with prior literature, although in the worker cohort from Chapter 1 and 2 participants were not asked about mask or eye protection type, and we are therefore limited in the ability to recommend a certain type of mask usage. For example, workers may have reported the use of a surgical mask, bandana, or full-face respirator, and all would have been counted equally. However, since a protective effect was observed, and the effect size may have been driven toward the null by lesser quality face protection, it makes the case even more compelling that masks are indeed beneficial for IHO workers. On-the-job training should be conducted to ensure those who are using PPE are using the equipment properly, with intervention trials conducted.

Policy changes should not rely solely on the addition or bolstering of PPE programs. In the hierarchy of controls framework published by NIOSH, PPE is the control measure that should be the least relied upon. Via both spirometry and reported symptoms our work showed the negative impacts to the respiratory system from on-IHO work activities and barn conditions. By improving barn conditions through proper and increased ventilation, dust mitigation, removal of pig waste, temperature control, and increased handwashing human health conditions may improve. This work also suggests that job tasks should be rotated so that one person is not performing all work that places them in close contact with pigs or that keeps them inside facilities for prolonged periods.

The use of ventilation fans has been proposed as one measure to control ambient air temperatures and dust within barns. While it may be beneficial to those working inside barns this control measure may actually cause worse impacts on the health and well-being of people living near IHOs. Pig waste has been documented outside and inside neighboring homes and is a detriment to property values and the ability to use property. By pushing more waste outside and offsite, these impacts may increase. One proposed option, and area for continued research, is the use of "scrubbers" or biofilters placed on ventilation fans to remove particulates and microbes leaving IHO barns.[190] Suppressing dust via an oil mist in barns also has been proposed,[191,192] with evidence that oil mists may also reduce carbon dioxide and methane concentrations as well.[193]

Other options have been successfully implemented by Smithfield in a Missouri-based operation[194] and deserve further research. They include hog slat scraper systems that remove waste from barns without adding extra water to lagoons, advanced nitrification-denitrification of hog waste, methane capture from covered lagoons, environmental buffers around IHOs, worker training, and reduction in herd size.

Conclusions

This dissertation adds evidence that IHO work activities pose dangers for workers' respiratory health in the long-term and via short-term transient exposures. Through community-generated survey and spirometry data we can document respiratory impacts as well as the IHO conditions and work activities contributing to these impacts. Notably, the increase in work activities and activities where people are in close contact with pigs and working in extremely hot and/or dusty barn conditions cause workers to wear coveralls but doff their face protection. The removal of face protection is a serious concern and deserves attention from employers and regulators alike. Further, a strong framework for those who want to conduct similar research for use in occupational health priority setting and community policy advocacy has been laid.

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CURRICULUM VITAE

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EDUCATION

JOHNS HOPKINS UNIVERSITY, Baltimore, MD
Bloomberg School of Public Health
Department of Environmental Health and Engineering
Exposure Science and Environmental Epidemiology Program
Doctoral Candidate (PhD degree conferral expected: November 2018)
Certificate in Risk Sciences and Public Policy, October 2016
Certificate in Food System, Environment, and Public Health, May 2017
Certificate in Public Health Informatics (Conferral expected: November 2018)
Awarded: National Institute for Occupational Safety and Health (NIOSH) Education and Research Center Pre-Doctoral Traineeship; Johns Hopkins Center for a Livable Future-Lerner Fellowship

UNIVERSITY OF CALIFORNIA, BERKELEY, Berkeley, CA
School of Public Health, Environmental Health Sciences Division
Global Health and Environment Program
Master of Science, December 2011
Thesis: Lead content of retail jewelry: an analysis of products sold in California and the performance of state and federal lead regulations
Awarded: University of California Graduate Scholarship

DEPAUL UNIVERSITY, Chicago, IL
Environmental Science Department
Bachelor of Science (emphasis in Public Policy), Minor in Chemistry, June 2008
Thesis: Earthworm impacts on restoration efforts in buckthorn (*Rhamnus cathartica*) invaded soils
Awarded: Clare Boothe Luce Scholarship and President's Fellowship

RESEARCH AND PUBLIC HEALTH WORK EXPERIENCE

Expert Consultant **November 2017 – present**
Natural Resources Defense Council (NRDC)
Washington DC

- Drawing extensively from the skills gained from PhD dissertation work, provide technical expertise on community-based participatory research (CBPR) regarding sensitive environmental public health data collection related to food animal production in rural areas.

- Establish research protocols, recommend analytic approaches, identify areas of opportunity for collaboration, analyze data, and convey findings to program leaders.

Consumer Representative **July 2015 – present**
The National Advisory Committee on Microbiological Criteria for Foods (NACMCF)
United States Department of Agriculture

- Collaborate with a distinguished multi-industry and agency team to deliver impartial scientific evidence on complex national food safety problems.
- As sole consumer representative, provide consumer perspective on recommendations and the dissemination of findings to the public.

Research Assistant **January 2015 – present**
Johns Hopkins Center for a Livable Future (CLF)
Baltimore, MD

- Research, compile, and disseminate time-sensitive media articles to CLF listserv members each day, prioritizing those needing immediate response.
- Interpret scientific articles published by CLF staff and to-date have written more than 30 press releases on their content.
- Previously, conducted phone interviews with subject matter experts to assemble a rapid-needs assessment for CLF's Food Animal Atlas.
- Analyzed and presented qualitative data gathered during the interviews to project managers.

Senior Policy Coordinator, Food Safety **January 2014 – August 2014**
STOP Foodborne Illness
Chicago, IL

- Served as a representative on the Consumer Advisory Board of the U.S. Department of Agriculture/National Institute of Food and Agriculture (USDA/NIFA)-funded STEC Coordinated Agricultural Project grant.
- Traveled extensively to Washington, DC to communicate with U.S. Food and Drug Administration (FDA), USDA, and Food Safety and Inspection Service (FSIS) officials and met with six Congressional offices to discuss the state of food safety in their states and/or districts.
- Composed and submitted formal oral and written comments on three proposed federal food safety regulations.
- Provided advice and support to victims of foodborne illness before and during their testimony to Congressional panels.
- Collaborated with industry experts to write a guidance document concerning traceability.
- Gave a radio interview (KRVN) concerning the need for consumer participation in food safety discourse.
- Served as City of Chicago Consumer Advisory Policy Board Member and on three national consumer health coalitions pursuing public-private partnerships to address food safety issues.

- Served as a Consumer Education, Protection & Vulnerable Consumers Policy Subcommittee Member for the Consumer Federation of America.

Education Manager **October 2012 – January 2014**
STOP Foodborne Illness
Chicago, IL

- Gave an interview to ABC national news; later invited to participate as an expert contributor in live ABC Tweet Chat and subsequent Twitter chat for the Centers for Disease Control and Prevention (CDC).
- Composed and submitted formal oral and written comments on five proposed federal food safety regulations.
- Counseled and assisted victim advocates during advocacy events.
- Coordinated an Executive Board committee to produce the organization's first-ever policy manual.
- Developed five new fact sheets and food safety literature to disseminate electronically and for placement in doctors' offices and hospitals.
- Presented at three educational seminars, with 100% requesting future speaking engagements.
- Proposed and conducted research detailing the financial impacts of foodborne illnesses.
- Worked with industry experts to write and advise on a published journal article, a blog post, and a white paper.
- Contributed to content and editing of a number one trending petition on Change.org (*Congress: Keep Chinese chicken out of our schools and supermarkets!*) with more than 300,000 signatures, 40,000 of which were garnered in one day.
- Assisted in the coordination of an on-IHO/on-facility meeting in Salinas, CA with leafy green producers, packers, and *Escherichia coli* victims to discuss the future of food safety with the Leafy Greens Marketing Association.

Surveillance and Abatement Team Member **April 2012 – October 2012**
August 2011 – October 2011
Vector Disease Control International in partnership with the City of Chicago Department of Public Health
Chicago, IL

- Served as a media spokesperson for TV interviews (Telemundo, ABC7 Chicago, and Univision) and responded to citizen complaints and inquiries.
- Performed field- and laboratory-based epidemiologic research aimed to protect Chicagoans from West Nile Virus; work included collecting biospecimens, speciation via microscopy, protein isolation, qRT-PCR, data entry, mapping outbreaks in Geographic Information Systems (GIS), interpreting vector density reports, and logging detailed observations and quantitative data for published City maps and formal reports.
- Conducted educational outreach in underserved communities during fifteen health fairs.

Senior Project Coordinator **November 2009 – July 2010**
Davis Projects for Peace: Enabling Vision
Bolivia, South America

- Proposed, obtained funding for, executed, and evaluated an international aid program including fiscal compliance with stated objectives and regulations.
- Distributed more than 600 pairs of eyeglasses to people unable to afford prescriptions.
- Fostered relationships with local and international non-governmental organizations, government officials, and volunteers.

Research Assistant **September 2009 – May 2010**
Center for Environmental Health (CEH)
Oakland, CA

- Collected samples and analyzed the heavy metal content of consumer goods via x-ray fluorescence.
- Cleaned and maintained the CEH database, comprising more than 9,000 individual items.
- Monitored coverage of findings in the Associated Press and in local and national TV news and talk show broadcasts about consumer safety.

International Research Intern **June 2008 – October 2008**
Food and Agricultural Organization of the United Nations (FAO)
Freetown, Sierra Leone

- Collected and synthesized past and current geographic and demographic data to determine rice production capacity and demand trends.
- Created maps, charts, and graphs to visually represent complex findings, which were incorporated into an FAO white paper *The Republic of Sierra Leone National Sustainable Agriculture Plan: 2010-2030*.
- Represented FAO in meetings and training sessions in Sierra Leone and neighboring nations.

<u>ADJUNCT TEACHING EXPERIENCE</u>

Organic Chemistry **September 2013 – December 2013**
DePaul University
Chicago, IL

Principles of Environmental Science **January 2012 – April 2013**
East-West University
Chicago, IL

<u>TEACHING ASSISTANT EXPERIENCE</u>

Teaching Assistant

Johns Hopkins University
Baltimore, MD

<u>Course</u>: *Environmental Epidemiology Journal Club*	**Q1-4 2017**
<u>Course</u>: *Methods in Quantitative Risk Assessment*	**Q3 2017**
<u>Course</u>: *Food Production, Public Health & the Environment*	**Q2 2017**
<u>Course</u>: *Topics in Risk Assessment*	**Q4 2017**
<u>Course</u>: *Environmental and Occupational Epidemiology*	**Q4 2017**
<u>Course</u>: *Food and Waterborne Diseases*	**Q3 2017**
<u>Course</u>: *Food System Sustainability Practicum*	**Q4 2016**
<u>Course</u>: *Environmental Epidemiology Journal Club*	**Q1-4 2016**
<u>Course</u>: *Food and Waterborne Diseases*	**Q3 2016**
<u>Course</u>: *Fundamentals of Occupational Health*	**Q1 2016**
<u>Course</u>: *Case Studies in Food Production and Public Health*	**Q4 2015**

<u>SKILLS</u>

- Conversational Spanish
- Public speaking and media communications to scientific and non-scientific audiences
- Community-based participatory research (CBPR)
- Program and project planning, in-field project management, and swift problem solving
- Social media for nonprofit organizations
- University-level teaching
- Grant writing
- Data analysis and management in STATA, R, Atlas.ti, REDCap, and Excel
- ArcGIS and Basic HTML coding
- qPCR and cell culture
- Air sampling

<u>SCIENTIFIC PRESENTATIONS AND PUBLICATIONS</u>

Papers

- Feng, P., Coffman, V.R., Gombas, D., Linton, R., Muriana, P., Ocasio, W., Onifande, T., Ruby, J., Ruple, A., Tauxe, R., O'Brien, A. (2017). National Advisory Committee on Microbiological Criteria for Foods (NACMCF) Subcommittee on Virulence Factors and Attributes that Define Foodborne Shiga Toxin-producing *Escherichia coli* (STEC) as Severe Human Pathogens. *Journal of Food Protection.* In press.
- Coffman, V., Plunkett, D.W., Wilson, G., Warren, W. (2014). The Food Safety Modernization Act – A Series on what is Essential for a Food Professional to Know. Article 7. Laboratory Accreditation. *Food Protection Trends*, 34(1): 44-48.
- *Subject matter reviewer:* Zhang, J., & Bhatt, T. (2014). A guidance document on the best practices in food traceability. *Comprehensive Reviews in Food Science*

and Food Safety, 13(5), 1074-1103. http://www.ift.org/~/media/GFTC/Best Practices Paper.pdf

- *Contributions to:* Down the Regulatory Rabbit Hole: How Corporate Influence, Judicial Review and a Lack of Transparency Delay Crucial Rules and Harm the Public. Coalition for Sensible Safeguards. (2013). *Whitepaper.* http://sensiblesafeguards.org/assets/documents/down-the-regulatory-rabbit-hole.pdf
- *Contributions to:* The Republic of Sierra Leone National Sustainable Agriculture Plan: 2010-2030 (2009). Food and Agricultural Organization of the United Nations (FAO). *Whitepaper*. http://extwprlegs1.fao.org/docs/pdf/sie158614.pdf
- Coffman, V. (2008). Earthworm impacts on restoration efforts in buckthorn (*Rhamnus cathartica*) invaded soils. *Creating Knowledge: The LA&S Student Research Journal* 1: 20-22.

Presentations

- Whole Genome Sequencing: the consumers' perspective. (2017). Use of Whole Genome Sequence (WGS) Analysis to Improve Food Safety and Public Health. *United States Department of Agriculture/Food Safety and Inspection Service public meeting.*
- Use of source-tracking methods to understand antimicrobial-resistant *S. aureus* exposure pathways among industrial hog operation workers and community residents. (2017). *International Society of Exposure Science conference.* Durham, NC.
- Work activities, self-reported symptoms, and diminished lung function in a population of predominantly Hispanic industrial hog operation workers in North Carolina, USA. (2017). *International Society of Environmental Epidemiology conference.* Sydney, Australia.
- Consumers and consumer advocates play a vital role in reducing the public health burden attributed to STEC illnesses. (2014). *Governor's Conference.* Lincoln, NE.
- Food Safety from a Laboratory Perspective: What you need to know to protect yourself and your brand. Co-presented with Mr. Mark Carter, CEO MC2E Inc. (2014). *Food Labs Conference.* Chicago, IL.
- Food Safety in Social Media: Don't be the last to know #thereisaproblem. Co-presented with Mr. Raed Mansour, City of Chicago. (2013). *Food Safety Consortium.* Chicago, IL.
- Illegally imported products: A danger to American consumers and overseas producers. (2011). *Undergraduate Public Health Coalition Annual Health Fair.* University of California, Berkeley.
- Earthworm impacts on restoration efforts in buckthorn (*Rhamnus cathartica*) invaded soils. (2008). *Chicago Area Undergraduate Research Symposium*. Chicago, IL.

Posters

- *Staphylococcus aureus* exposure and diminished lung function in industrial hog workers in North Carolina. (2016). *International Society of Environmental Epidemiology Conference*. Rome, Italy.
- Lack of Antibiotic Resistance Confirmation and Tracebacks Are a Detriment to Patients: Using Survivors' Stories to Illustrate the Problem. (2013). *Seventh Annual Research Conference*. University of Toledo College of Nursing.
- Lead-Contaminated Jewelry in the U.S. (2011). *Global Health: Breaking Borders and Boundaries conference*. University of California, Davis.

Abstracts

- Coffman, V.R., Hall, D., McCormack, M.C., Heaney, C.D. (2017). Work activities, self-reported symptoms, and diminished lung function in a population of predominantly Hispanic industrial hog operation workers in North Carolina, USA. *Epidemiology*.
- Coffman, V.R., Pisanic, N., Hall, D., Love, D., Davis, M.F., Heaney, C.D. (2016). *Staphylococcus aureus* exposure and diminished lung function in industrial hog workers in North Carolina. *Environmental Health Perspectives.*

CERTIFICATIONS

- Certified in Public Health (*Provisional*)
- Certified in NIOSH-approved spirometry (03/2016)

PROFESSIONAL MEMBERSHIPS

- International Society of Environmental Epidemiologists (ISEE)
- International Society of Exposure Scientists (ISES)